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ACIDIC PRECIPITATION IN ONTARIO STUDY

AIR CONCENTRATION AND DRY DEPOSITION FIELDS OF POLLUTANTS IN ONTARIO, 1982

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AIR CONCENTRATION AND DRY DEPOSITION FIELDS OF POLLUTANTS IN ONTARIO - 1982

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1. INTRODUCTION

As part of the pollutant deposition monitoring effort of the Acidic Precipitation in Ontario Study (APIOS), air concentrations of selected pollutants over 28 day intervals have been determined using a low-volume filtration method since late 1981. By 1982, there were 23 air sampling stations in Ontario as part of this study. The purpose of these measurements is to estimate the dry deposition rate of these pollutants using the air concentration, and deposition velocity.

A description of the cumulative air monitoring network siting, instrumentation and analytical methods is given in another document (Chan, et. al. 1984a)

In this report, 1982 annual concentration contours across Ontario of the measured pollutants (SO_2, $SO_4^{=}$, NO_3^-, Fe, Al, Ca^{++}, Mg^{++}, K^+, Cu, Ni, Pb, Zn, Mn, Cd, V, Na^+ and Cl^-) are presented. The individual data on which the present work is based have been published elsewhere (Ontario Ministry of the Environment, 1984). For substances such as sulfur and nitrogen oxides, for which deposition velocity values are relatively well known, dry deposition contours are also calculated. Furthermore, these dry deposition data were compared with the published wet deposition data (Chan et al. 1984b) to determine the relative importance of wet and dry deposition in Ontario. For a number of other substances, deposition velocites have been estimated, based on their particle size distributions measured at various locations in Ontario. These deposition velocities can be used, in conjunction with their air concentration contours, to estimate their dry deposition rates (albeit with a large uncertainty). A brief discussion is also included on the seasonal variation of the the ambient concentrations and dry deposition rates of the sulfur and nitrogen oxides.

2. DATA PREPARATION

2.1 Air Concentration Results

Data used in the 1982 annual contour calculations correspond to 13 sampling periods beginning on January 5, 1982 and ending on January 4, 1983. Table 1 summarizes the geometric mean concentrations of the measured pollutants using all the available data at each monitoring site. Figure 1 shows the sampling stations that are identified in Table 1. (The numbering of the stations is not consecutive as only 23 out of the 36 precipitation sampling stations of the cumulative network are equipped with air filtration instrumentation). Mean values derived from less than 8 out of the 13 sampling periods are underlined and are not used in the calculation of contours.

2.2 Dry Deposition Results

The dry deposition rate is calculated according to:

$$Dep = C_{av} \times V_d$$

where Dep = dry deposition rate
C_{av} = geometric mean air concentration
V_d = deposition velocity.

The biggest problem in estimating dry deposition rates is probably not due to the uncertainty in the air concentrations, but rather the deposition velocity. Because of the larger uncertainty in the deposition velocity values for pollutants other than sulfur and nitrogen oxides, only dry deposition of sulfur and nitrogen oxides is calculated and reported

here. In this work, the deposition velocities of the sulfur compounds were estimated using the method of Masse and Voldner (1983), as recently updated by Voldner et al. (1985), which is an extension of the approach by Sheih et al. (1979). For sulfur dioxide, deposition velocities are similar to those of Sheih et al. on an annual basis; for sulfate, they are considerably lower, but in basic agreement with more recent work (Wesely and Shannon, 1984). Using this method, and information on local surface coverage and (interpolated) meteorological data at each of the sites shown in Figure 1, annual and seasonal average deposition velocities were determined. These values vary across Ontario and are summarized in Figures 2 and 3. For $SO_4^=$ annual average deposition velocities were in the range 0.14 - 0.40 cm s^{-1}; for SO_2, values lay in the 0.17 - 0.38 cm s^{-1} range. Seasonal variations are discussed by Masse and Voldner (1983).

Estimating the dry deposition rate of nitrates involves an additional complication, in that there is a contribution from both nitric acid vapor and particulate nitrates. These two species are expected to have quite different deposition rates, that of nitric acid being greater, and are largely determined by atmospheric transport to the surface, with little canopy resistance (Huebert and Robert, 1985). A detailed study has not yet been undertaken into the distribution of nitrates between the particulate and vapor forms in Ontario. However, air measurements on a daily basis, using the filter pack technique (with a teflon filter for particulates, a nylon filter for nitric acid, and a pair of potassium carbonate impregnated filters for sulfur dioxide) at four different locations in the Ontario daily network, indicate that except for southern Ontario, nitric acid dominates the particulate nitrates by a factor of two or more in the ratio of the two forms of nitrate with no clear seasonal variation (Ontario Ministry of the Environment, 1983; Kirk, 1983). In southern Ontario, where there may be more interaction of nitric acid

vapor with windblown dust (due to agricultural and other anthropogenic activities), the two forms are of comparable importance. For the purposes of this study, it was assumed that all the nitrates exist as nitric acid, and their deposition is governed by atmospheric transport, with no canopy resistance. This led to deposition velocities of around 1.0 cm s^{-1} in southern Ontario and generally in the 1.5 - 3.4 cm s^{-1} range in central and northern Ontario (see Figure 4) and probably resulted in an overestimate of the nitrate dry deposition rate (since particulate nitrates are expected to have a lower deposition velocity than nitric acid).

Dry deposition results for $S\text{-}SO_2$, $S\text{-}SO_4^{=}$ and $N\text{-}NO_3^{-}$ are summarized in Table 2. Again, results corresponding to less than 8 sampling periods are underlined.

Deposition contours are not generated for the trace metals for which air concentrations are reported here. This is mainly due to the fact that deposition velocities of these metals are not well studied and few experimental values are reported in the literature. An attempt has been made to examine past particle sizing work done by the Ministry of the Environment at different locations in Ontario, namely, in the Sudbury area (Ash Street, Burwash, Penage, Happy Valley and Long Lake - Chan et al. 1982), Toronto, Dorset (Ontario Ministry of the Environment, 1985), Cheapside and Long Point (Kiely and Sahota, 1985). Deposition velocities were calculated using information on V_d as a function of particle size reported by McMahon and Dennison (1979). This was done by weighing the V_d for a given size range by the corresponding fraction of the total mass in that size range. A summary of the deposition velocities so calculated is given in Table 3. It should be noted that a large variability exists in these values; hence large uncertainties can be expected if the V_d values shown in the Table are used to calculate dry deposition rates.

3. RESULTS AND DISCUSSION

Results from Tables 1 and 2 are presented as annual air concentration and dry deposition contours in this section. In all contour figures, the station numbers are given on the bottom left hand corner for each of the monitoring stations whereas the results are indicated on the top right hand corner. Stations with no data are indicated by an asterisk. A modified Kriging scheme (Tang and Chan, 1985) was used in the generation of the contour plots.

The 1982 contour results are also of particular interest as the Sudbury smelters were shut down in the latter half of 1982. Separate reports assessing the impact of the Sudbury smelters on air concentration and dry deposition have been prepared (Tang, et al., 1984, Yap and Kurtz, 1984). Where appropriate, brief remarks are made in this report with respect to the shutdown impact on the results.

3.1 Air Concentration Contours

3.1.1 S-$SO_4^=$ and S-SO_2

Figures 5 and 6 show the air concentration contours of S-$SO_4^=$ and S-SO_2 respectively. Values in southern Ontario, near sources of anthropogenic emissions, are considerably higher than those in the northern part of the province. The gradient in sulfur dioxide concentration with distance from the emission areas is greater than that for sulfates, which is as expected, since sulfur is emitted primarily as

sulfur dioxide, and conversion to sulfates proceeds relatively slowly. On an annual basis, roughly one-quarter of the atmospheric sulfur in southern Ontario exists in the particulate form, but in northern Ontario the proportions in particulate and gaseous forms are more comparable.

Figure 7 corresponds to contours of total airborne sulfur. Again a south to north negative gradient is observed with a factor of about 8 variation in concentration. However, the contours are more regular as compared to those of $S\text{-}SO_2$ and $S\text{-}SO_4^{=}$.

3.1.2 $N\text{-}NO_3^-$

Figure 8 shows the contours of $N\text{-}NO_3^-$ concentration. The $N\text{-}NO_3^-$ corresponds to the total nitrate concentration - the sum of particulate nitrates (W40 filter) and HNO_3 (nylon filter). A fairly regular south to north negative gradient is observed with a change of concentration from the southernmost to the northernmost regions by a factor greater than 10.

3.1.3 Fe, Al, Ca, Mg and K (Figures 9 to 13)

These parameters are grouped together because they are all soil-related. Patterns of the contours for Fe, Al, Ca, and Mg are all irregular but similar. Stations along the SW Ontario to SE Ontario axis adjacent to the lakes have somewhat higher concentrations, probably because these stations are in agricultural areas. Relatively high local concentrations are observed at stations #22 and #30 for Fe (0.24 and 0.20

ug m^{-3}), Al (0.13 and 0.06 ug m^{-3}) and Mg (0.11 and 0.13 ug m^{-3}), and at stations #13 and #30 for Ca (0.92 and 0.47 ug m^{-3}), suggesting possible local contamination. The pattern for K, however, is more regular showing a south to north decrease. Relatively low concentrations are observed at stations #9 (0.43 ug m^{-3}) and #20 (0.38 ug m^{-3}). Generally, the concentration gradient (south to north) for these substances is much smaller than that for the sulfur and nitrogen compounds measured.

3.1.4 Cu and Ni (Figures 14 and 15)

The contour patterns for Cu and Ni are similar especially in central and southern Ontario. Values along the SE and SW Ontario border are somewhat higher than those inland. Cu concentration is typically 3 times higher than that of Ni. Although there is no clear evidence of impact of the Sudbury smelters, the relatively higher Cu (1.97 ng m^{-3}) and Ni (0.72 ng m^{-3}) concentration at station #23 (Killarney) SW of Sudbury may possibly be an indication of smelter influence. It should be noted that Cu and Ni are good tracers of smelter emissions, and have shown a major smelter impact in the atmospheric deposition within the Sudbury Basin itself (Chan et. al., 1984c).

3.1.5 Pb, Zn, Mn, Cd and V

Pb, Zn and Mn display similar concentration profiles (Figures 16 to 18). There exists a south to north negative gradient (up to 7 to 10 fold concentration changes) in all cases and concentration values along the SE and SW Ontario border are higher than those inland. At stations #22 (7.96 ng m^{-3}) and #30 (4.92 ng m^{-3}), the concentration of Mn is anomalously high with respect to the neighboring areas. This is probably due to high airborne soil constituent concentrations, since several other soil-related parameters (Fe, Al, Ca) are also relatively high at these stations.

The Cd (Figure 19) contours are quite irregular with an anomalously high value at station #25 (0.85 ng m^{-3}). There is little change in the V concentration (Figure 20) across the province compared to that of the other parameters; concentrations are mostly on the order of 1 ng m^{-3} or less. In SE and SW Ontario there exists an east to west negative gradient. The results for V are somewhat surprising as airborne V is largely due to oil combustion and the observed gradient is not aligned with the predominant wind direction.

3.1.6 Na and Cl (Figures 21 and 22)

Somewhat unexpected and contrary to what is observed in the precipitation concentration and wet deposition fields, contours of these parameters are not similar. There exists a west to east positive gradient (except along the SE/SW Ontario border) for Na whereas in the case of Cl, a S to N negative gradient is observed.

3.2 Dry Deposition Contours

3.2.1 S-$SO_4^=$ and S-SO_2

Figures 23 and 24 are dry deposition contours of $SO_4^=$ and SO_2 plotted using results from Table 2. In both cases, there is a general decrease in dry deposition from south to north. As can be seen in Table 2 and Figures 23 and 24, most of the sulfur d-y deposition comes from sulfur dioxide, because of its generally higher concentrations and deposition velocities. As a consequence of this, the profile of the total S dry deposition as shown in Figure 25 resembles that of SO_2.

3.2.2 $N\text{-}NO_3^-$

Figure 26 represents contours of dry deposition of $N\text{-}NO_3^-$ using data in Table 2. They are basically similar to those of air concentration except with some relatively high values in central Ontario due to high deposition velocity values. In general, there is a decrease in dry deposition from south to north with a change up to a factor of 8

3.3 Comparison of Wet and Dry Deposition Rates

A comparison of sulfur and nitrogen wet and dry deposition fields for 1982 in Ontario is made here using wet deposition results reported elsewhere (Chan et al., 1984b). Wet deposition contours of sulfur and nitrogen are shown in Figures 27 and 28, and may be compared with the corresponding dry deposition rates in Figures 25 and 26. It should be noted that the nitrogen dry deposition values are based only on air measurements of nitrates, and not species such as nitrogen dioxide and nitric oxide, which probably contribute significantly to the atmospheric burden of nitrogen compounds. (On the other hand, recall that our estimates of nitrate dry deposition, based on the assumption that all nitrates exist as nitric acid, are probably high, so there may be some compensation of errors).

The total provincial deposition of sulfur and nitrogen was calculated using the contours in Figures 25 to 28 for dry and wet deposition, and information on the areas of the various census districts in the province. A representative value of dry and wet deposition rate was assigned for each district, and then multiplied by the area of the district to give the annual

deposition over the district. The sum of all the district deposition values then gave the provincial total. This comparison shows that wet deposition of sulfur is about five times greater than dry deposition. For nitrogen, wet and dry deposition are more comparable across the province in favor of the former. Given the uncertainties in sulfur and nitrogen wet and dry deposition rates alluded to in Section 2, the error in the sulfur and nitrogen total deposition figures in Table 4 could be as high as 40 and 60% respectively. It is interesting to note that our estimates of provincial wet and dry deposition are in reasonable agreement with some values presented by Niemann (1983), which were based on a much more limited data set for 1980, except that our results show a sulfur wet deposition rate that is higher by almost a factor of two than Niemann's.

3.4 Seasonal Variation

Results have been rearranged to obtain seasonal concentration averages for winter 81/82 (November 30/81 to March 2/82), spring 82 (March 3/82 to May 25/82), summer 82 (May 26/82 to September 14/82) and autumn 82 (September 15/82 to December 7/82). Tables 5 to 8 summarize these results. In these tables, stations with no data during the season of interest are labelled with a dot (.) whereas those with only 1 value (winter 81/82, spring 82 and autumn 82) and 1 or 2 values only (summer 82) are underlined.

Because the seasonal pattern is non-uniform for all stations and all parameters, no general conclusions are given here except for sulfur and nitrogen compounds. Readers interested in the specific details for other parameters are referred to Tables 5 to 8.

During the winter, there is a strong dominance of gaseous over particulate sulfur, especially in central and southern Ontario. During the summer, particulate sulfur concentration levels become much more important. The above observations are no doubt due to the lower ventilation (Portelli, 1977) and chemical transformation rates of sulfur during the winter as compared to the summer. It is interesting to note that the secondary pollutants, sulfates and nitrates, display similar seasonal variations, with comparable summer and wintertime levels in southern Ontario, but higher levels during winter than summer in the northern portions of the province.

Sulfur dry deposition rates tend to be higher during the winter than the summer (even though deposition velocities show the opposite trend), because of the relatively high sulfur dioxide concentrations during winter. Nitrate dry deposition rates tend to be more comparable throughout the year, except in northern Ontario, where wintertime values are larger than those during the other seasons.

4. CONCLUSIONS

Air measurements were made of sulfur and nitrogen compounds, some major ions, and a number of trace metals in Ontario in 1982. Based on reported deposition velocities, dry deposition rates of sulfur and nitrogen were calculated. However, due to the scarcity and uncertainty of the trace metal deposition velocity data, their corresponding dry deposition rates were not reported. The readers can infer these based on air concentrations and the compiled deposition velocities, though with a large uncertainty in the results.

A severalfold variation was noted in the concentration and deposition of airborne sulfur and nitrogen compounds across the province, being highest in the south, near the emission source areas. The observations also show the influence of meteorological factors (e.g., ventilation rate) and seasonal changes in atmospheric chemistry.

Wet deposition of sulfur was found to be about three to four times higher than dry deposition near source areas, and about five times greater on a province-wide basis. For nitrogen, wet and dry deposition were estimated to be of similar magnitude.

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TABLE 1 :
GEOMETRIC MEAN CONCENTRATION(UG/M**3) - 1982 *

ID	SO2	SO4	S	N_NO3	CL	CA	MG	K	NA	FE	AL	PB	MN	CU	NI	V	ZN	CD
1	12.33	5.30	10.05	1.33	0.63	0.60	0.188	0.089	0.151	0.161	0.078	0.075	0.0111	0.0043	0.00115	0.0014	0.044	0.00065
3	8.78	5.15	8.27	1.17	0.43	0.52	0.120	0.078	0.123	0.151	0.076	0.050	0.0105	0.0020	0.00074	0.0010	0.024	0.00044
4	12.86	5.83	8.85	1.49	0.77	0.98	0.205	0.101	0.219	0.174	0.118	0.064	0.0138	0.0026	0.00087	0.0015	0.038	0.00072
8	5.03	4.76	4.29	0.91	0.41	0.64	0.192	0.072	0.131	0.135	0.082	0.051	0.0083	0.0020	0.00060	0.0009	0.021	0.00054
9	3.20	3.21	2.94	0.57	0.25	0.26	0.068	0.043	0.108	0.065	0.032	0.025	0.0040	0.0016	0.00059	0.0008	0.010	0.00031
10	6.40	3.16	4.22	0.76	0.41	0.59	0.201	0.075	0.121	0.142	0.059	0.112	0.0096	0.0024	0.00193	0.0007	0.029	0.00028
11	4.19	2.33	3.77	0.61	0.34	0.27	0.042	0.068	0.100	0.062	0.031	0.029	0.0043	0.0013	0.00061	0.0008	0.009	0.00024
13	3.74	3.88	3.42	0.61	0.29	0.92	0.079	0.061	0.119	0.117	0.087	0.052	0.0072	0.0019	0.00122	0.0010	0.016	0.00044
14	2.76	2.18	2.44	0.33	0.24	0.16	0.037	0.063	0.095	0.082	0.030	0.022	0.0038	0.0019	0.00079	0.0010	0.010	0.00033
15	3.88	3.02	3.22	0.46	0.27	0.67	0.222	0.062	0.122	0.105	0.071	0.049	0.0101	0.0020	0.00117	0.0015	0.016	0.00056
16	2.80	2.97	2.87	0.58	0.35	0.58	0.074	0.061	0.150	0.101	0.062	0.057	0.0075	0.0031	0.00198	0.0023	0.019	0.00052
17	2.86	2.57	2.83	0.27	0.16	0.16	0.046	0.056	0.149	0.076	0.037	0.028	0.0036	0.0024	0.00086	0.0010	0.009	0.00063
20	2.73	3.28	2.93	0.40	0.19	0.16	0.046	0.038	0.111	0.084	0.051	0.022	0.0034	0.0015	0.00052	0.0007	0.010	0.00039
21	2.43	2.47	2.16	0.37	0.17	0.14	0.036	0.057	0.122	0.061	0.030	0.019	0.0028	0.0017	0.00052	0.0008	0.010	0.00035
22	1.90	2.50	2.01	0.24	0.18	0.16	0.108	0.055	0.146	0.244	0.132	0.028	0.0080	0.0022	0.00060	0.0008	0.013	0.00027
23	3.48	2.94	2.76	0.44	0.15	0.16	0.049	0.060	0.148	0.090	0.045	0.025	0.0041	0.0020	0.00072	0.0008	0.011	0.00047
25	2.97	2.35	2.48	0.24	0.12	0.12	0.059	0.043	0.121	0.097	0.054	0.019	0.0035	0.0029	0.00058	0.0007	0.012	0.00085
27	1.48	1.61	1.46	0.12	0.15	0.18	0.054	0.032	0.140	0.056	0.029	0.010	0.0021	0.0012	0.00057	0.0007	0.008	0.00045
28	1.34	2.16	1.53	0.16	0.35	0.19	0.088	0.059	0.230	0.041	0.016	0.014	0.0026	0.0012	0.00057	0.0009	0.016	0.00035
30	0.94	1.56	1.08	0.08	0.17	0.47	0.126	0.037	0.109	0.199	0.060	0.015	0.0049	0.0016	0.00053	0.0007	0.006	0.00014
31	0.63	1.19	0.70	0.08	0.11	0.13	0.065	0.045	0.103	0.061	0.053	0.007	0.0027	0.0010	0.00058	0.0007	0.004	0.00012
35	0.65	0.90	0.64	0.12	0.14	0.12	0.054	0.026	0.100	0.078	0.046	0.011	0.0025	0.0011	0.00068	0.0009	0.005	0.00016
36	0.73	0.75	0.58	0.06	0.18	0.11	0.039	0.011	0.109	0.057	0.026	0.009	0.0014	0.0018	0.00053	0.0009	0.004	0.00011

* ID = station number (see Figure 1)
Values underlined correspond to data which are less than two-third complete.

Table 2

1982 Annual Dry Deposition ($g\ m^{-2}\ y^{-1}$) of S- and N-Compounds in Ontario*

Area	Site Number	$S\text{-}SO_4^{=}$	$S\text{-}SO_2$	$N\text{-}NO_3^{-}$
Southern Ontario	1	0.17	0.70	0.27
	3	0.08	0.32	0.33
	4	0.15	0.65	0.33
	8	0.09	0.20	0.29
	9	0.06	0.12	0.18
	10	0.10	0.26	0.29
	11	0.05	0.16	0.24
	13	0.12	0.17	0.27
	14	0.08	0.07	0.31
Central Ontario	15	0.08	0.12	0.31
	16	0.06	0.07	0.21
	17	0.09	0.08	0.25
	20	0.09	0.07	0.39
	21	0.10	0.14	0.12
	22	0.09	0.05	0.21
	23	0.12	0.11	0.44
Northern Ontario	25	0.08	0.08	0.24
	27	0.05	0.04	0.10
	28	0.04	0.06	0.03
	30	0.04	0.03	0.05
	31	0.04	0.02	0.07
	35	0.03	0.02	0.10
	36	0.02	0.02	0.05

* Values underlined correspond to stations with less than 8 out of the 13 sampling period data.

Table 3
Summary of Calculated Deposition Velocities (cm s^{-1})
of Trace Metals in Ontario

Parameters	No. of Sites	Mean	(Std. Dev.)	Max.	Min.
Fe	9	1.04	(0.22)	1.40	0.80
Ni	6	0.99	(0.40)	1.41	0.35
Cu	9	0.59	(0.22)	0.94	0.17
Pb	8	0.31	(0.10)	0.43	0.13
Zn	9	0.25	(0.09)	0.37	0.13
Al	8	0.89	(0.26)	1.23	0.51
Cd	7	0.29	(0.07)	0.38	0.18
Mn	5	0.69	(0.19)	1.01	0.20
Ca	7	1.18	(0.14)	1.43	0.95
Mg	8	0.78	(0.38)	1.33	0.16

Table 4

Comparison of S- and N-
Deposition Rates for 1982 in Ontario

	Sulfur	Nitrogen
Deposition ($T_g\ y^{-1}$)		
Wet	0.51	0.18
Dry	0.10	0.11
Total	0.61	0.29

TABLE 5:
GEOMETRIC MEAN CONCENTRATION(UG/M**3)*

SEASON = WINTER 81/82 (DEC 81 - FEB 82)

ID	SO2	SO4	S	N_NO3	CL	CA	MG	K	NA	FE	AL	PB	MN	CU	NI	V	ZN	CD
1	31.39	6.01	17.73	1.62	0.80	0.38	0.121	.	.	0.205	0.072	0.081	0.0118	0.0039	0.00195	0.0021	0.044	0.00074
3	30.08	5.74	17.00	1.76	0.70	0.41	0.108	.	.	0.126	0.070	0.058	0.0142	0.0034	0.00136	0.0020	0.033	0.00092
4	29.28	5.52	15.95	1.67	0.84	0.54	0.074	.	.	0.173	0.096	0.068	0.0097	0.0033	0.00063	0.0017	0.042	0.00104
8	11.24	4.86	7.78	0.93	0.56	0.30	0.117	.	.	0.100	0.057	0.047	0.0063	0.0022	0.00099	0.0014	0.019	0.00093
9	13.37	4.16	8.07	1.01	0.24	0.12	0.041	.	.	0.057	0.022	0.025	0.0049	0.0019	0.00047	0.0013	0.020	.
10	9.36	3.18	5.74	0.92	0.44	0.26	0.097	.	.	0.091	0.021	0.073	0.0067	0.0024	0.00061	0.0005	0.017	0.00060
11	6.25	0.55	3.34	0.49	0.28	0.03	0.007	.	.	0.027	0.018	0.011	0.0035	0.0010	0.00072	0.0007	0.002	0.00030
13	10.70	3.35	6.47	0.76	0.38	0.19	0.032	.	.	0.079	0.049	0.053	0.0059	0.0030	0.00047	0.0011	0.006	0.00140
14	6.45	2.93	4.22	0.50	0.41	0.09	0.028	.	.	0.067	0.031	0.018	0.0056	0.0030	0.00066	0.0015	0.009	0.00087
15	4.56	1.72	3.32	0.39	0.19	0.14	0.058	.	.	0.046	0.021	0.039	0.0062	0.0023	0.00145	0.0021	0.012	0.00144
16	2.62	3.09	3.39	0.95	0.56	0.18	0.036	.	.	0.066	0.027	0.053	0.0136	0.0027	0.00336	0.0086	0.016	0.00114
17	9.48	1.96	5.39	0.49	0.18	0.04	0.024	.	.	0.067	0.031	0.032	0.0035	0.0024	0.00134	0.0019	0.007	0.00109
20	6.48	2.72	4.25	0.49	0.20	0.04	0.023	.	.	0.041	0.018	0.023	0.0021	0.0029	0.00066	0.0005	0.009	0.00096
21	12.27	2.87	7.09	0.49	0.38	0.10	0.039	0.059	0.337	0.046	0.022	0.033	0.0019	0.0010	0.00043	0.0008	0.016	0.00094
22	5.78	2.58	4.21	0.29	0.10	0.09	0.049	0.057	0.235	0.082	0.029	0.040	0.0038	0.0029	0.00037	0.0009	0.021	0.00102
23	14.22	3.53	8.37	0.52	0.23	0.16	0.058	0.080	0.241	0.092	0.033	0.033	0.0035	0.0028	0.00085	0.0012	0.017	0.00120
25	4.64	3.00	4.34	0.28	0.21	0.07	0.036	0.049	0.192	0.032	0.013	0.020	0.0014	0.0025	0.00036	0.0006	0.013	0.00106
27	4.69	1.66	2.91	0.16	0.26	0.10	0.051	0.047	0.229	0.037	0.015	0.014	0.0018	0.0006	0.00031	0.0006	0.014	0.00065
28	2.71	2.28	2.12	0.11	0.39	0.14	0.094	.	0.310	0.029	0.012	0.018	0.0027	0.0022	0.00036	0.0010	0.022	0.00049
30	3.25	1.74	2.21	0.13	0.14	0.06	0.037	0.099	0.179	0.052	0.020	0.023	0.0022	0.0017	0.00049	0.0005	0.005	0.00036
31	3.24	1.69	2.08	0.15	0.13	0.07	0.045	0.131	0.215	0.042	0.031	0.011	0.0020	0.0008	0.00091	0.0007	0.004	0.00042
35	1.78	1.34	1.35	0.14	0.17	0.03	0.037	0.045	0.187	0.037	0.025	0.024	0.0009	0.0024	0.00091	0.0007	0.004	0.00044
36	1.24	2.11	2.68	0.10	0.30	0.02	0.040	.	0.287	0.040	0.032	0.017	0.0013	0.0036	0.00033	.	0.007	0.00048

* ID = station number (see Figure 1)
Values underlined correspond to data which are less than two-third complete.

TABLE 6 :

GEOMETRIC MEAN CONCENTRATION(UG/M**3) *

SEASON = SPRING 82 (MAR - MAY)

ID	SO2	SO4	S	N_NO3	CL	CA	MG	K	NA	FE	AL	PB	MN	CU	NI	V	ZN	CD
1	13.45	5.95	8.71	1.53	0.60	0.51	0.153	0.050	0.222	0.123	0.074	0.081	0.0100	0.0084	.	0.0008	0.040	0.00077
3	9.03	5.53	7.31	1.47	0.48	0.68	0.154	0.056	0.162	0.227	0.173	0.040	0.0151	0.0024	0.00154	0.0010	0.027	0.00056
4	6.75	9.14	5.77	1.75	0.92	2.46	0.526	0.116	0.290	0.550	0.323	0.051	0.0288	0.0022	0.00208	0.0017	0.052	0.00132
8	5.45	4.91	4.56	1.33	0.37	0.59	0.183	0.060	0.134	0.142	0.097	0.044	0.0093	0.0018	0.00058	0.0007	0.025	0.00080
9	4.11	2.24	2.82	0.65	0.21	0.20	0.051	0.016	0.106	0.058	0.039	0.016	0.0038	0.0023	0.00078	0.0007	0.007	0.00105
10	6.54	2.14	4.02	0.57	0.36	0.42	0.140	0.032	0.118	0.116	0.056	0.078	0.0049	0.0014	0.00188	0.0007	0.025	0.00015
11	3.91	2.68	5.77	0.81	0.38	0.17	0.043	0.045	0.094	0.051	0.022	0.013	0.0024	0.0008	0.00046	0.0007	0.006	0.00013
13	5.02	4.18	3.90	0.67	0.25	1.44	0.110	0.045	0.124	0.153	0.124	0.039	0.0092	0.0013	0.00069	0.0007	0.012	0.00038
14	3.92	0.61	2.17	0.29	0.24	0.09	0.013	0.054	0.106	0.043	0.006	0.006	0.0012	0.0024	0.00106	0.0009	0.007	0.00012
15	3.17	3.56	2.78	0.56	0.26	1.59	0.613	0.048	0.147	0.196	0.135	0.038	0.0163	0.0014	0.00052	0.0012	0.016	0.00249
16	1.23	0.75	0.86	0.26	0.22	2.29	0.131	0.013	0.128	0.090	0.026	0.011	0.0035	0.0044	0.00229	0.0009	0.028	0.00067
17	4.20	3.10	3.34	0.35	0.17	0.28	0.076	0.054	0.213	0.098	0.060	0.030	0.0060	0.0019	0.00052	0.0011	0.013	0.00122
20	6.13	3.57	4.27	0.48	0.18	0.21	0.059	0.037	0.111	0.104	0.082	0.025	0.0042	0.0018	0.00059	0.0008	0.011	0.00041
21	3.86	2.71	2.67	0.36	0.11	0.12	0.035	0.028	0.127	0.071	0.035	0.014	0.0033	0.0014	0.00052	0.0007	0.009	0.00048
22	2.54	2.29	2.09	0.20	0.15	0.11	0.066	0.033	0.092	0.192	0.097	0.016	0.0059	0.0020	0.00053	0.0006	0.008	0.00059
23	11.65	3.87	8.06	0.57	0.07	0.09	0.045	0.045	0.118	0.112	0.072	0.025	0.0055	0.0034	0.00085	0.0007	0.010	0.00078
25	3.31	2.80	2.77	0.27	0.08	0.11	0.073	0.028	0.092	0.159	0.089	0.018	0.0065	0.0023	0.00069	0.0006	0.011	0.00197
27	3.47	2.49	2.85	0.15	0.13	0.21	0.063	0.031	0.080	0.105	0.053	0.011	0.0045	0.0008	0.00046	0.0006	0.008	0.00077
28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
30	1.55	2.27	2.24	0.14	0.21	0.27	0.065	0.010	0.090	0.233	0.037	0.012	0.0037	0.0026	0.00056	0.0006	0.006	0.00011
31	1.76	2.41	1.68	0.16	0.09	0.11	0.033	0.046	0.148	0.045	0.028	0.015	0.0020	0.0013	0.00066	0.0007	0.007	0.00026
35	0.83	2.16	1.44	0.16	0.22	0.09	0.030	0.011	0.190	0.072	0.032	0.010	0.0021	0.0006	0.00096	0.0006	0.003	0.00009
36	1.63	1.09	1.26	0.07	0.44	0.16	0.040	0.003	0.106	0.063	0.031	0.015	0.0018	0.0013	0.00061	0.0008	0.003	0.00004

* ID = station number (see Figure 1)
Values underlined correspond to data which are less than two-third complete.

TABLE 7:
GEOMETRIC MEAN CONCENTRATION(UG/M**3) *

SEASON = SUMMER 82 (JUN - AUG)

ID	SO2	SO4	S	N_NO3	CL	CA	MG	K	NA	FE	AL	PB	MN	CU	NI	V	ZN	CD
1	6.68	5.00	4.55	1.21	0.57	0.79	0.256	0.090	0.121	0.170	0.080	0.058	0.0098	0.0041	0.00127	0.0011	0.035	0.00066
3	4.07	6.27	3.84	0.97	0.30	0.63	0.151	0.106	0.088	0.216	0.081	0.050	0.0115	0.0018	0.00055	0.0007	0.021	0.00042
4	4.42	10.37	5.67	2.05	0.73	2.37	0.966	0.112	0.150	0.176	0.107	0.068	0.0192	0.0043	0.00107	0.0021	0.038	0.00064
8	2.47	4.38	2.53	0.74	0.35	1.41	0.323	0.067	0.099	0.202	0.108	0.045	0.0098	0.0023	0.00043	0.0009	0.020	0.00054
9	1.18	3.64	1.83	0.39	0.25	0.38	0.098	0.056	0.097	0.078	0.038	0.018	0.0040	0.0015	0.00053	0.0009	0.009	0.00023
10	5.46	3.90	3.58	0.82	0.46	0.82	0.296	0.155	0.123	0.205	0.090	0.136	0.0133	0.0037	0.00338	0.0006	0.034	0.00043
11	2.43	4.96	2.93	0.63	0.30	1.04	0.090	0.094	0.095	0.125	0.069	0.054	0.0082	0.0020	0.00086	0.0008	0.019	0.00049
13	1.91	4.83	2.64	0.45	0.26	2.27	0.110	0.060	0.095	0.155	0.103	0.045	0.0088	0.0030	0.00259	0.0008	0.020	0.00035
14	1.54	3.44	1.94	0.28	0.16	0.28	0.054	0.061	0.077	0.108	0.060	0.046	0.0051	0.0019	0.00068	0.0007	0.009	0.00028
15	2.34	3.90	2.48	0.36	0.21	0.75	0.202	0.063	0.096	0.128	0.085	0.049	0.0085	0.0020	0.00240	0.0009	0.012	0.00024
16	2.06	3.32	2.17	0.34	0.22	0.65	0.110	0.060	0.111	0.144	0.100	0.058	0.0083	0.0025	0.00132	0.0012	0.015	0.00030
17	1.00	3.83	1.81	0.09	0.13	0.19	0.050	0.055	0.100	0.087	0.044	0.022	0.0042	0.0031	0.00137	0.0008	0.008	0.00040
20	1.25	3.66	1.87	0.28	0.15	0.17	0.051	0.041	0.095	0.122	0.081	0.022	0.0037	0.0019	0.00058	0.0006	0.008	0.00022
21	1.14	2.18	1.34	0.22	0.15	0.16	0.033	0.055	0.061	0.065	0.027	0.014	0.0026	0.0014	0.00068	0.0007	0.006	0.00017
22	1.03	2.77	1.47	0.14	0.18	0.23	0.186	0.064	0.103	0.478	0.384	0.033	0.0130	0.0015	0.00053	0.0007	0.010	0.00018
23	1.26	3.15	1.69	0.28	0.16	0.21	0.051	0.052	0.105	0.091	0.043	0.028	0.0039	0.0011	0.00057	0.0008	0.009	0.00022
25	1.51	2.37	1.58	0.12	0.10	0.15	0.078	0.035	0.080	0.171	0.118	0.015	0.0055	0.0038	0.00065	0.0008	0.010	0.00049
27	0.51	1.08	0.66	0.03	0.12	0.25	0.049	0.020	0.074	0.057	0.037	0.006	0.0014	0.0013	0.00062	0.0010	0.004	0.00020
28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
30	0.35	1.23	0.58	0.02	0.20	2.04	0.435	0.068	0.089	0.449	0.170	0.015	0.0099	0.0014	0.00066	0.0007	0.005	0.00011
31	0.33	0.68	0.35	0.03	0.09	0.16	0.122	0.038	0.072	0.092	0.105	0.005	0.0037	0.0008	0.00062	0.0007	0.003	0.00006
35	0.11	0.16	0.11	0.03	0.08	0.14	0.062	.	0.021	0.119	0.094	0.004	0.0031	0.0005	0.00039	0.0011	0.003	0.00014
36	0.38	0.53	0.37	0.02	0.16	0.20	0.048	0.033	0.092	0.085	0.032	0.005	0.0014	0.0025	0.00066	0.0012	0.004	0.00012

* ID = station number (see Figure 1)
Values underlined correspond to data which are less than two-third complete.

TABLE 8:
GEOMETRIC MEAN CONCENTRATION(UG/M**3)*

SEASON = AUTUMN 82 (SEPT - NOV)

ID	SO2	SO4	S	N_NO3	CL	CA	MG	K	NA	FE	AL	PB	MN	CU	NI	V	ZN	CD
1	11.02	.	.	1.29	0.62	0.77	0.211	0.134	0.150	0.202	0.100	0.113	0.0118	0.0043	0.00095	0.0026	0.048	0.00096
3	8.24	4.99	6.20	0.96	0.39	0.33	0.062	0.087	0.140	0.107	0.034	0.070	0.0048	0.0014	0.00039	0.0007	0.021	0.00030
4	15.34	3.97	8.99	1.03	0.57	0.67	0.078	0.083	0.188	0.046	0.030	0.085	0.0063	0.0013	0.00042	0.0008	0.027	0.00025
8	5.27	6.33	3.00	1.12	0.34	0.51	0.167	0.118	0.148	0.178	0.085	0.094	0.0085	0.0015	0.00074	0.0007	0.023	0.00052
9	3.99	3.89	3.38	0.72	0.29	0.28	0.063	0.082	0.110	0.080	0.025	0.050	0.0043	0.0012	0.00063	0.0008	0.015	0.00029
10	9.89	4.50	6.44	1.07	0.40	0.59	0.188	0.106	0.122	0.086	0.021	0.185	0.0139	0.0028	0.00039	0.0008	0.031	0.00050
11	7.16	2.42	4.84	0.62	0.32	0.32	0.039	0.059	0.110	0.043	0.018	0.048	0.0031	0.0013	0.00047	0.0009	0.013	0.00013
13	4.88	3.34	3.80	1.01	0.26	0.61	0.065	0.084	0.139	0.110	0.068	0.075	0.0073	0.0027	0.00096	0.0010	0.022	0.00049
14	2.45	.	.	.	.	0.22	0.042	0.082	0.168	0.092	0.030	0.061	0.0045	0.0010	0.00051	0.0010	0.014	0.00041
15	6.09	3.09	4.07	0.74	0.33	0.61	0.219	0.075	0.217	0.107	0.077	0.052	0.0117	0.0033	0.00042	0.0033	0.024	0.00117
16	3.48	4.18	4.04	1.10	0.35	0.60	0.059	0.088	0.157	0.112	0.070	0.077	0.0028	0.0040	0.00150	0.0034	0.025	0.00057
17	2.27	2.39	2.58	0.36	0.20	0.17	0.043	0.059	0.145	0.063	0.028	0.030	0.0031	0.0036	0.00074	0.0010	0.013	0.00039
20	1.82	3.23	2.65	0.53	0.23	0.16	0.033	.	0.117	0.054	0.025	0.020	0.0028	0.0008	0.00033	0.0007	0.013	0.00045
21	2.32	2.75	2.15	0.61	0.20	0.17	0.036	0.113	0.145	0.065	0.036	0.032	0.0032	0.0026	0.00047	0.0010	0.015	0.00040
22	1.19	2.49	1.65	0.36	0.16	0.19	0.115	0.065	0.197	0.224	0.103	0.027	0.0077	0.0033	0.00092	0.0010	0.018	0.00008
23	1.42	2.07	1.33	0.48	0.17	0.18	0.043	0.082	0.192	0.072	0.034	0.019	0.0041	0.0023	0.00091	0.0008	0.013	0.00041
25	2.56	2.15	2.13	0.36	0.17	0.13	0.046	0.085	0.151	0.080	0.050	0.025	0.0030	0.0029	0.00042	0.0008	0.015	0.00062
27	0.75	2.16	1.25	0.20	0.12	0.18	0.049	0.047	0.201	0.043	0.025	0.014	0.0020	0.0024	0.00133	0.0006	0.013	0.00052
28	0.66	2.03	1.10	0.25	0.27	0.30	0.101	0.059	0.170	0.048	0.027	0.014	0.0024	0.0005	0.00093	0.0007	0.013	0.00022
30	0.87	1.45	0.93	0.12	0.16	0.45	0.090	0.050	0.114	0.209	0.051	0.019	0.0035	0.0014	0.00036	0.0007	0.006	0.00009
31	0.61	1.31	0.77	0.10	0.13	0.14	0.042	0.069	0.119	0.047	0.030	0.008	0.0022	0.0016	0.00041	0.0008	0.003	0.00010
35	0.84	1.19	0.86	0.14	0.15	0.21	0.076	0.056	0.118	0.088	0.047	0.016	0.0041	0.0014	0.00043	0.0009	0.006	0.00011
36	0.31	0.56	0.34	0.06	0.13	0.15	0.033	0.028	0.107	0.047	0.014	0.010	0.0015	0.0009	0.00046	0.0009	0.001	0.00005

* ID = station number (see Figure 1)
Values underlined correspond to data which are less than two-third complete.

1 - COLCHESTER
2 - MERLIN
3 - PORT STANLEY
4 - WILKESPORT
5 - ALVINSTON
6 - HURON PARK
7 - WATERLOO
8 - PALMERSTON
9 - SHALLOW LAKE
10 - MILTON
11 - UXBRIDGE
12 - COLDWATER
13 - CAMPBELLFORD
14 - KALADAR
15 - SMITH'S FALLS
16 - DALHOUSIE MILLS
17 - GOLDEN LAKE
18 - WILBERFORCE
19 - WHITNEY
20 - DORSET
21 - MCKELLAR
22 - MATTAWA
23 - KILLARNEY
24 - BEAR ISLAND
25 - GOWGANDA
26 - RAMSEY
27 - MOONBEAM
28 - ATTAWAPISKAT
29 - WINISK
30 - NAKINA
31 - DORION
32 - QUETICO CENTRE
33 - LAC LA CROIX
34 - EXP. LAKES AREA
35 - EAR FALLS
36 - PICKLE LAKE

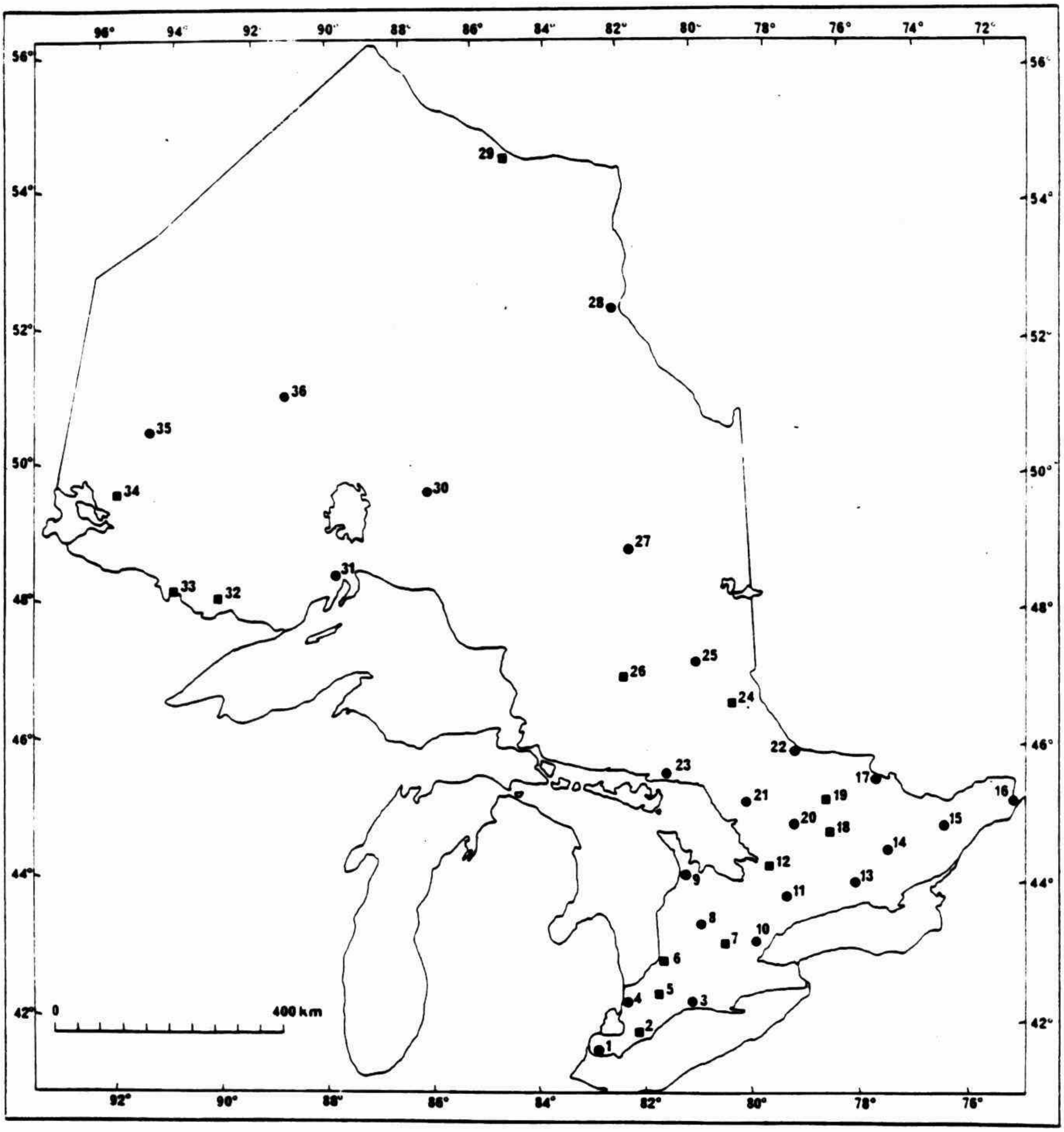

Figure 1: APIOS Cumulative Wet/Dry Deposition Network Station Location Map
(● air and precipitation; ■ precipitation only)

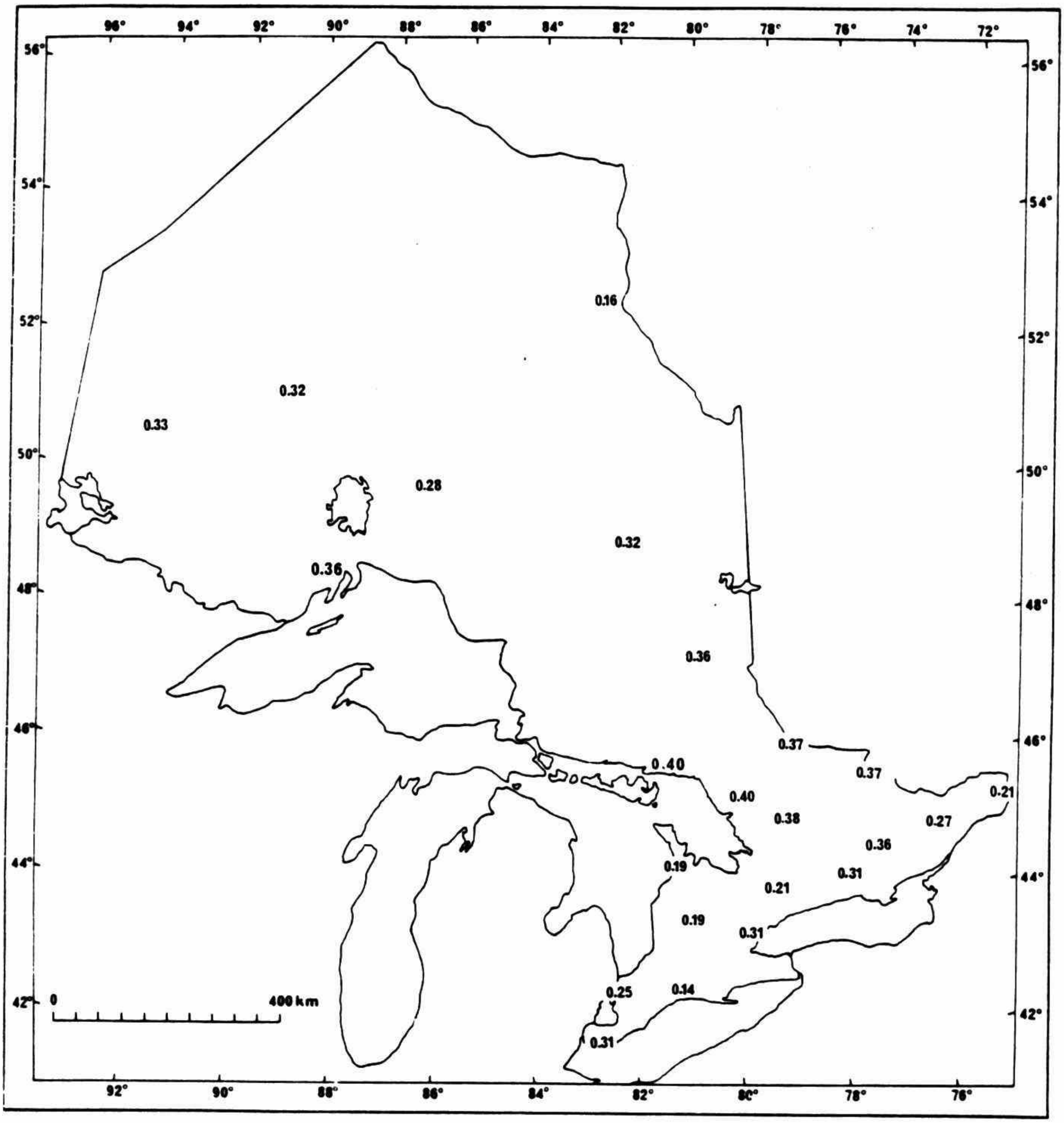

Figure 2: Annual Average Deposition Velocity of SO_4 ($cm\ s^{-1}$)

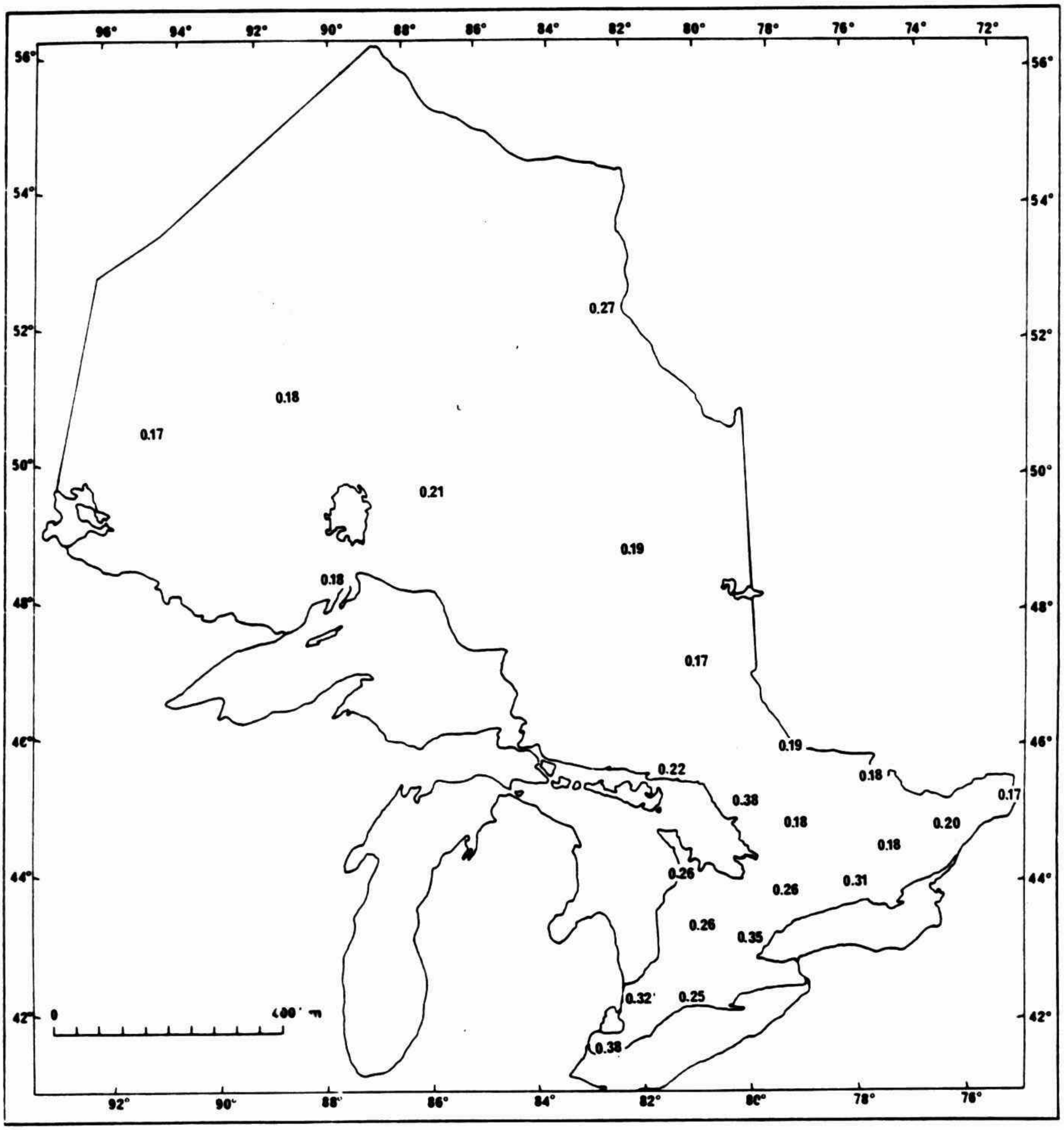

Figure 3: Annual Average Deposition Velocity of SO_2 (cm s^{-1})

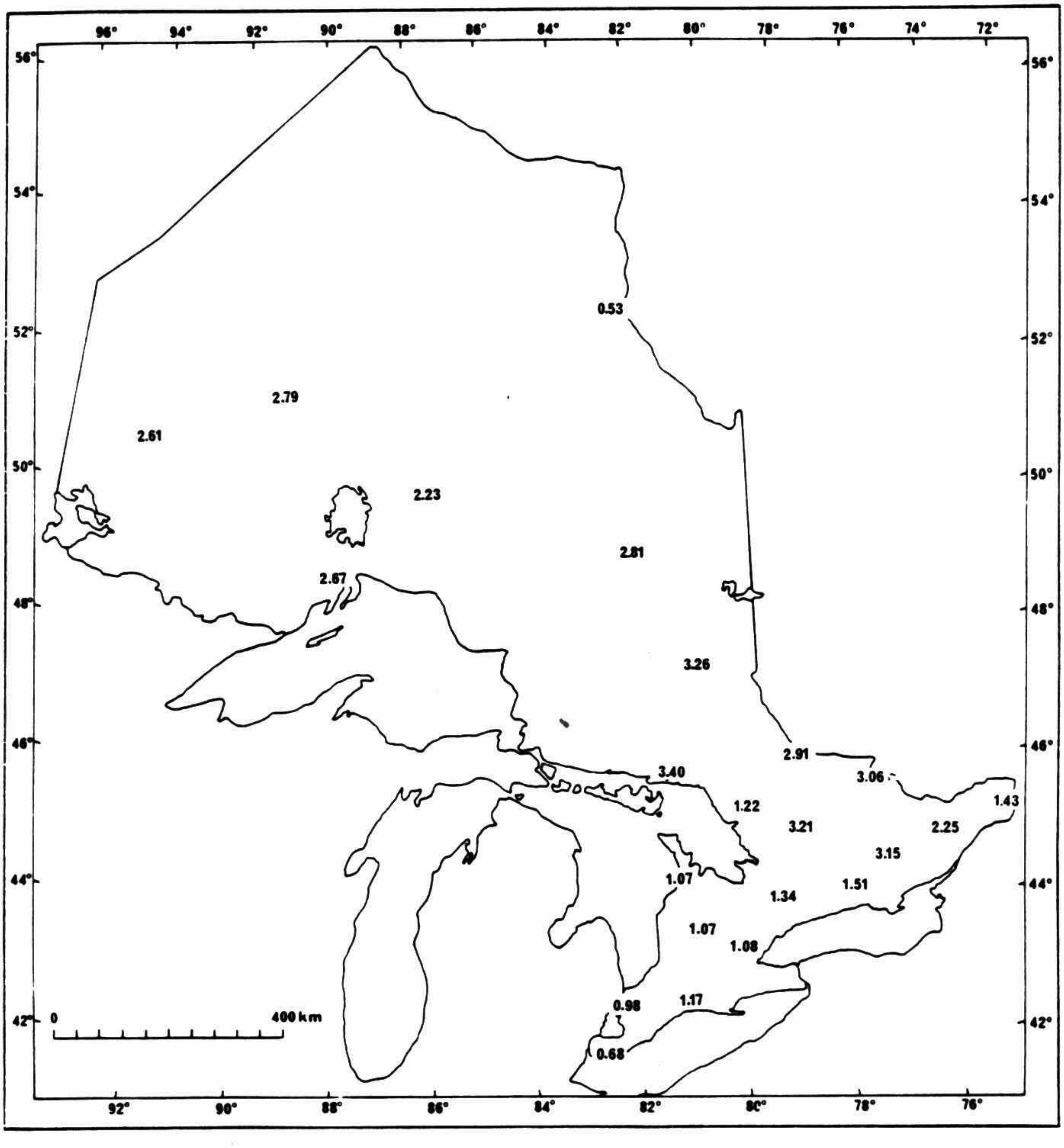

Figure 4: Annual Average Deposition Velocity HNO_3 (cm s^{-1})

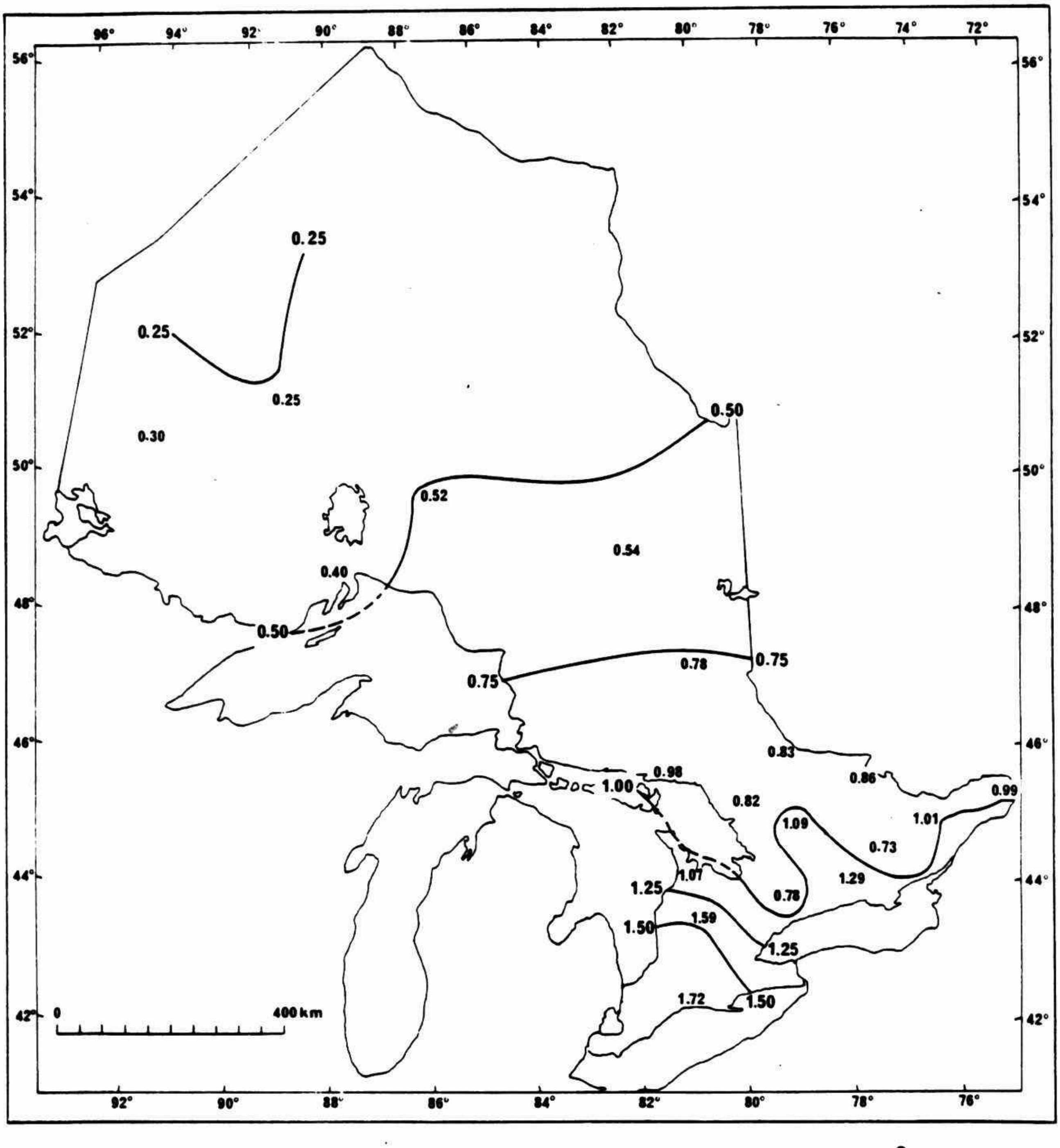

Figure 5: 1982 Annual Average Air Concentration of $SO_4^{=}$ (ug S m^{-3})

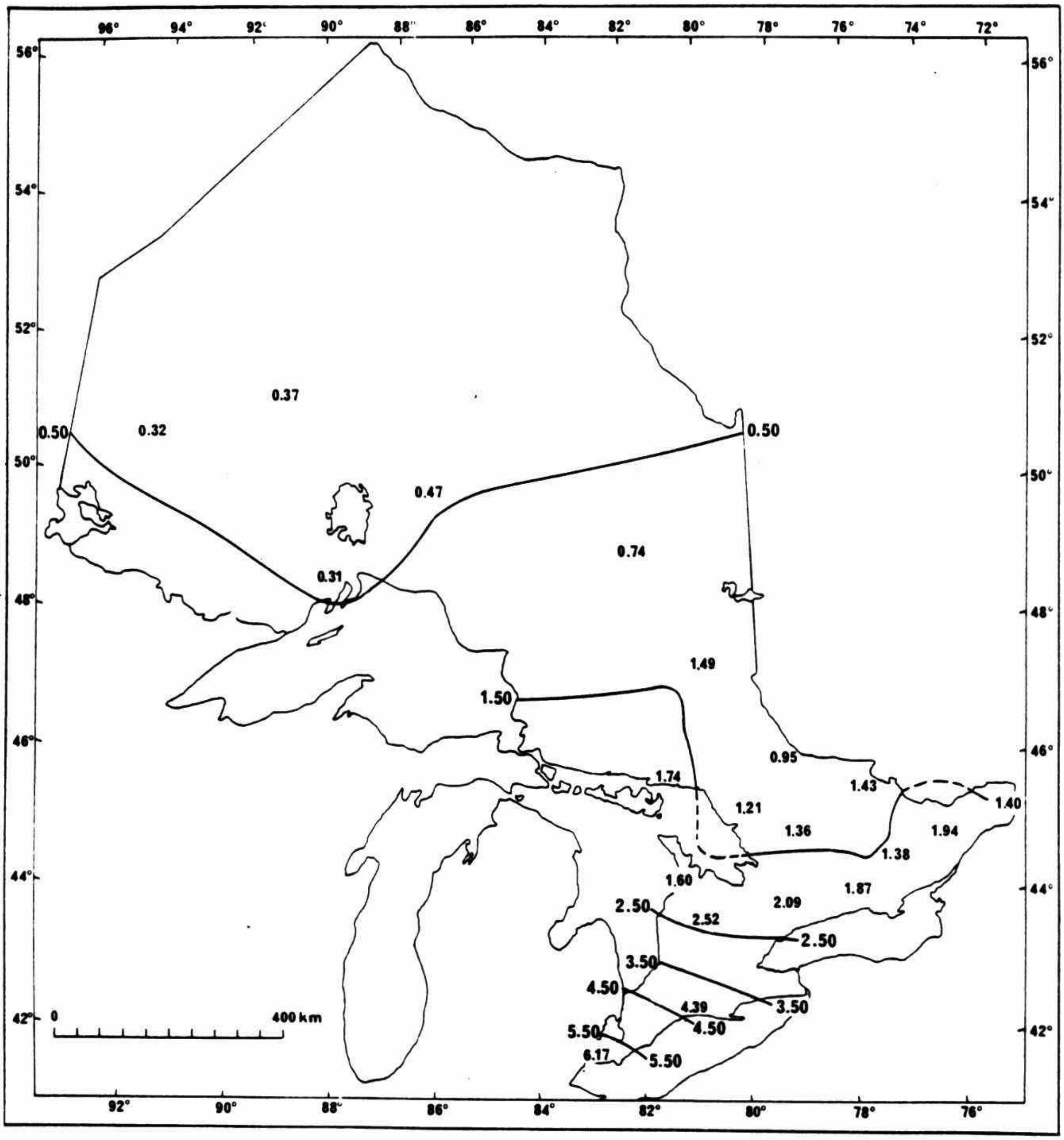

Figure 6: 1982 Annual Average Air Concentration of SO_2 (ug S m^{-3})

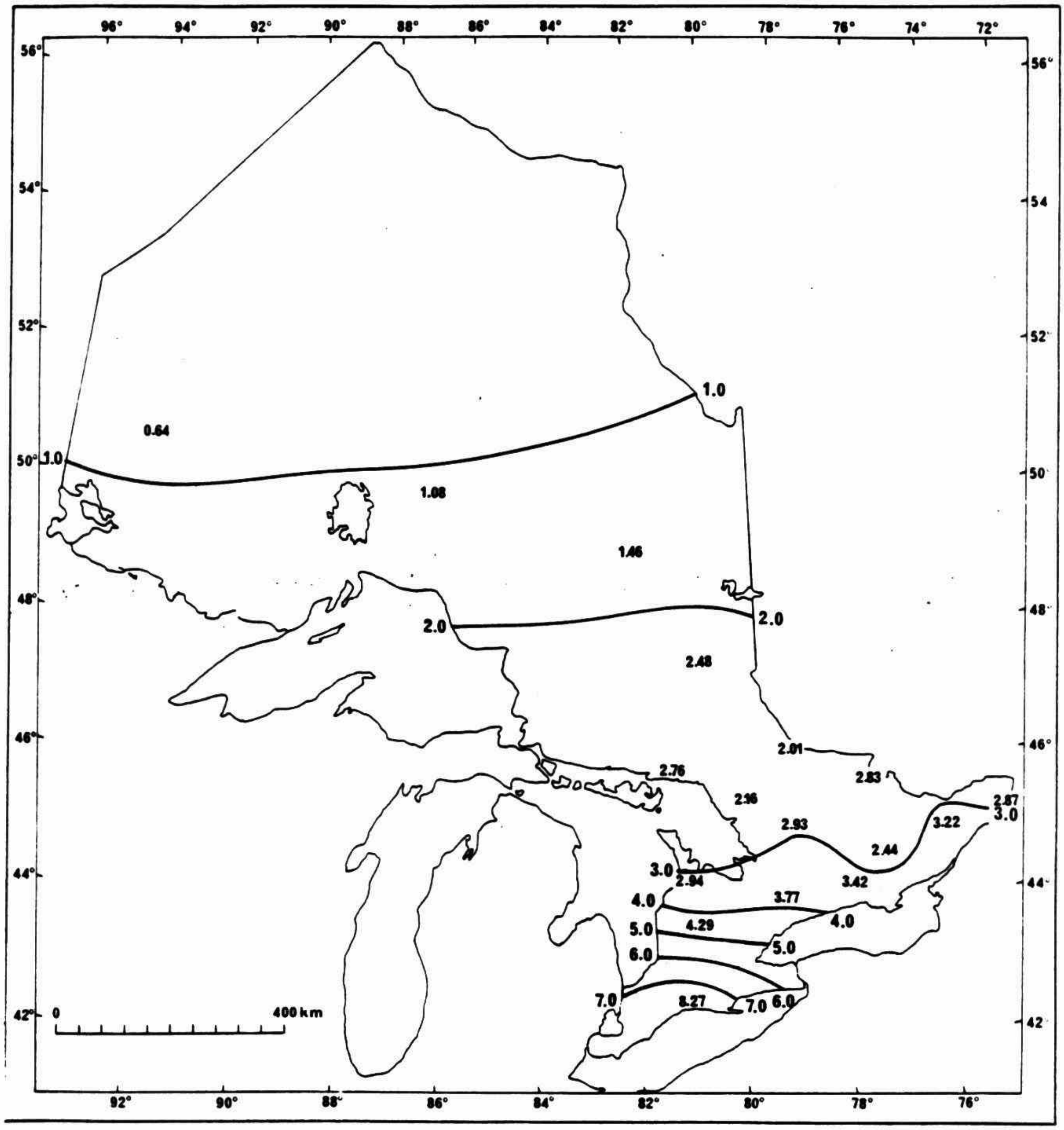

Figure 7: 1982 Annual Average Air Concentration of S (ug m^{-3})

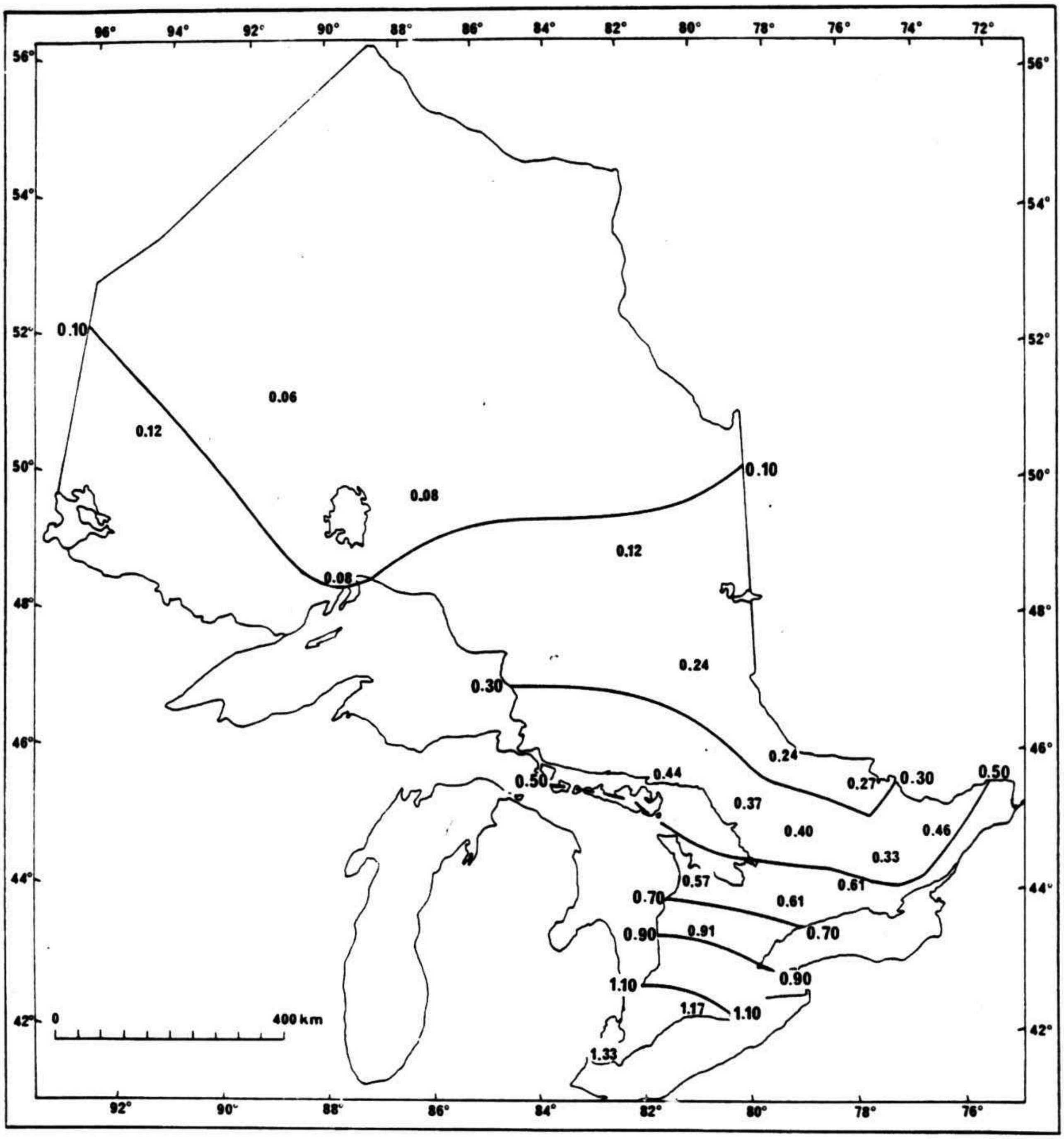

Figure 8: 1982 Annual Average Air Concentration of NO_3 (ug N m^{-3})

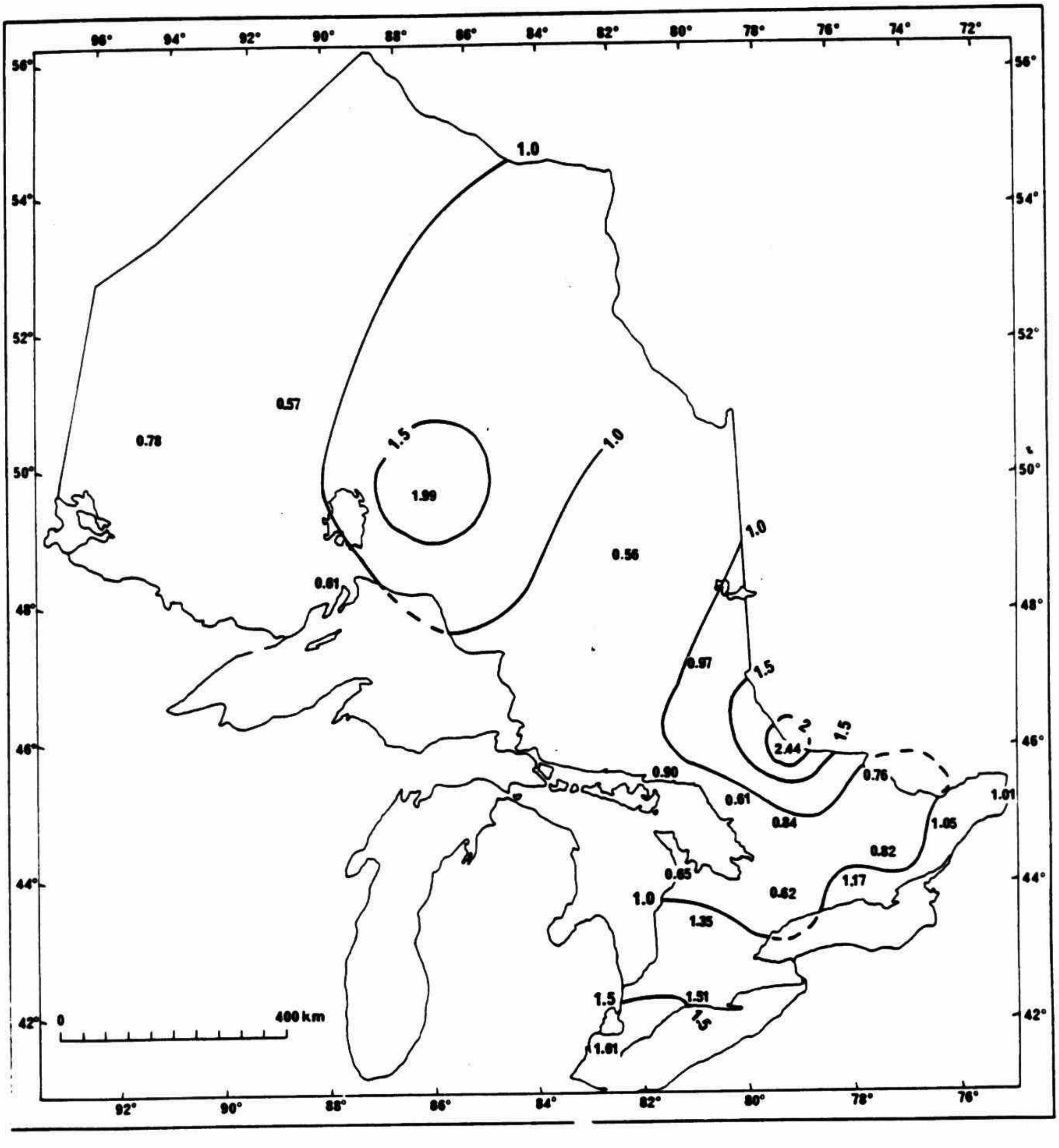

Figure 9: 1982 Annual Average Air Concentration of Fe (0.1 ug m^{-3})

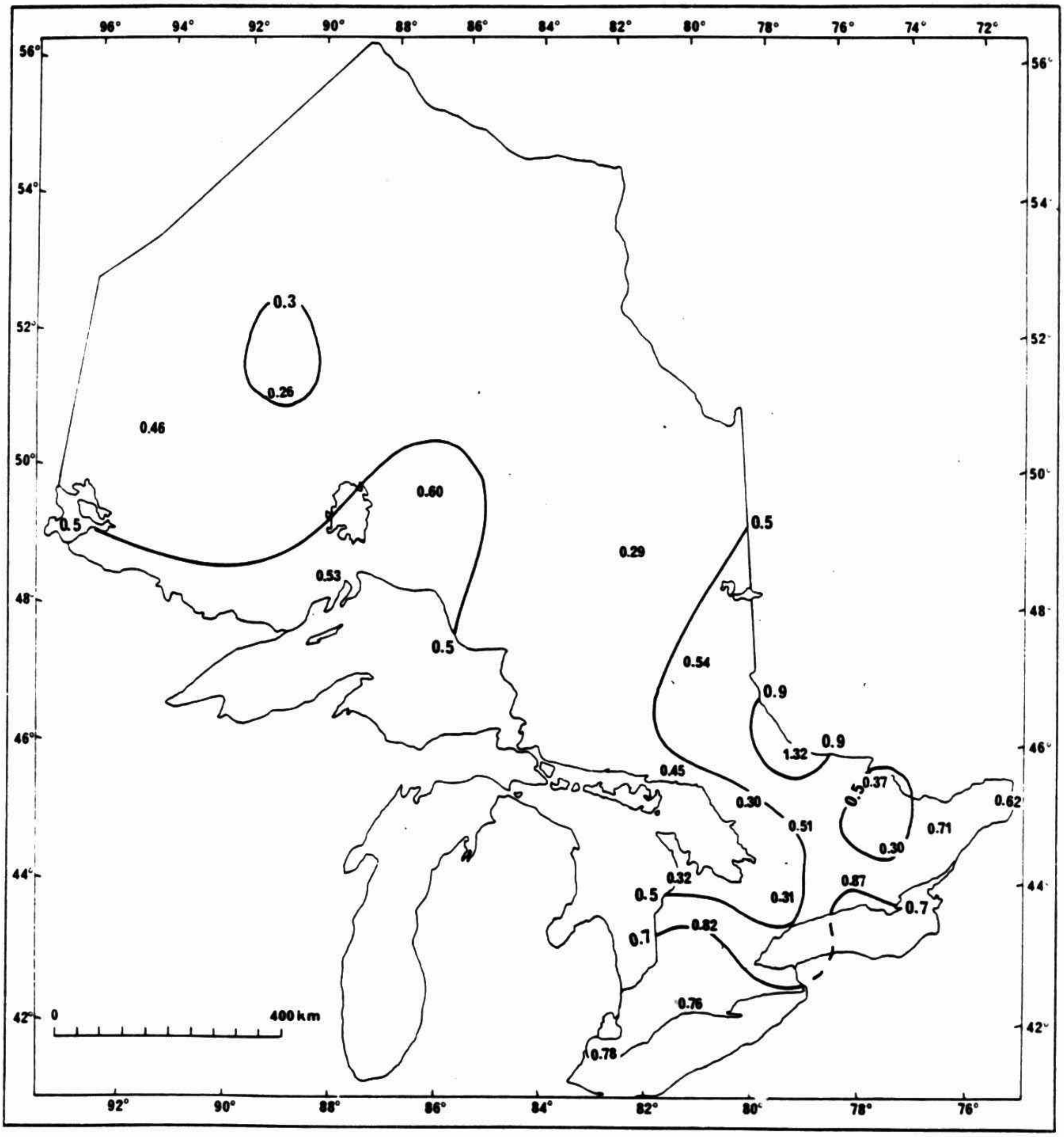

Figure 10: 1982 Annual Average Air Concentration of Al (0.1 ug m^{-3})

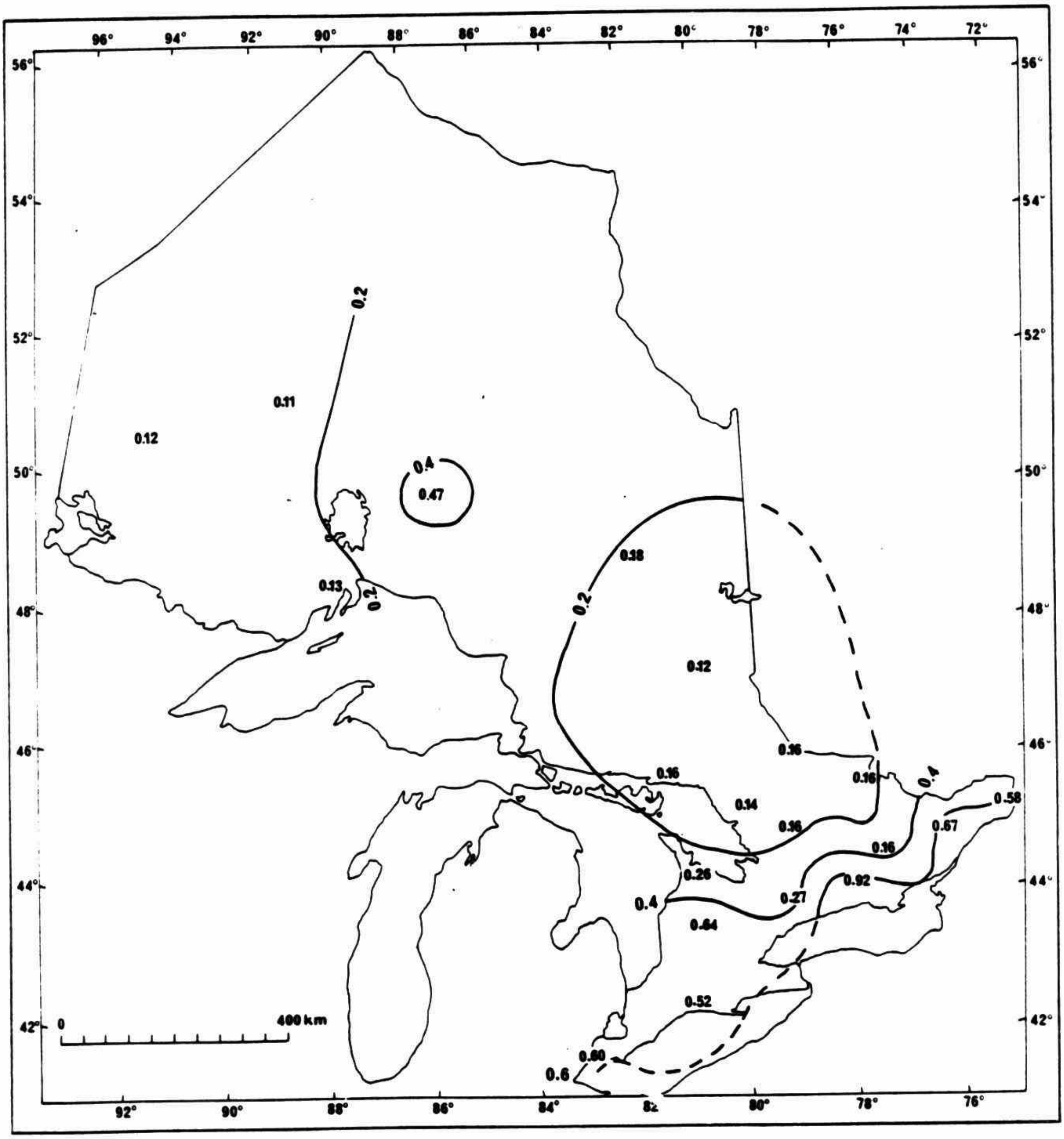

Figure 11: 1982 Annual Average Air Concentration of Ca (ug m^{-3})

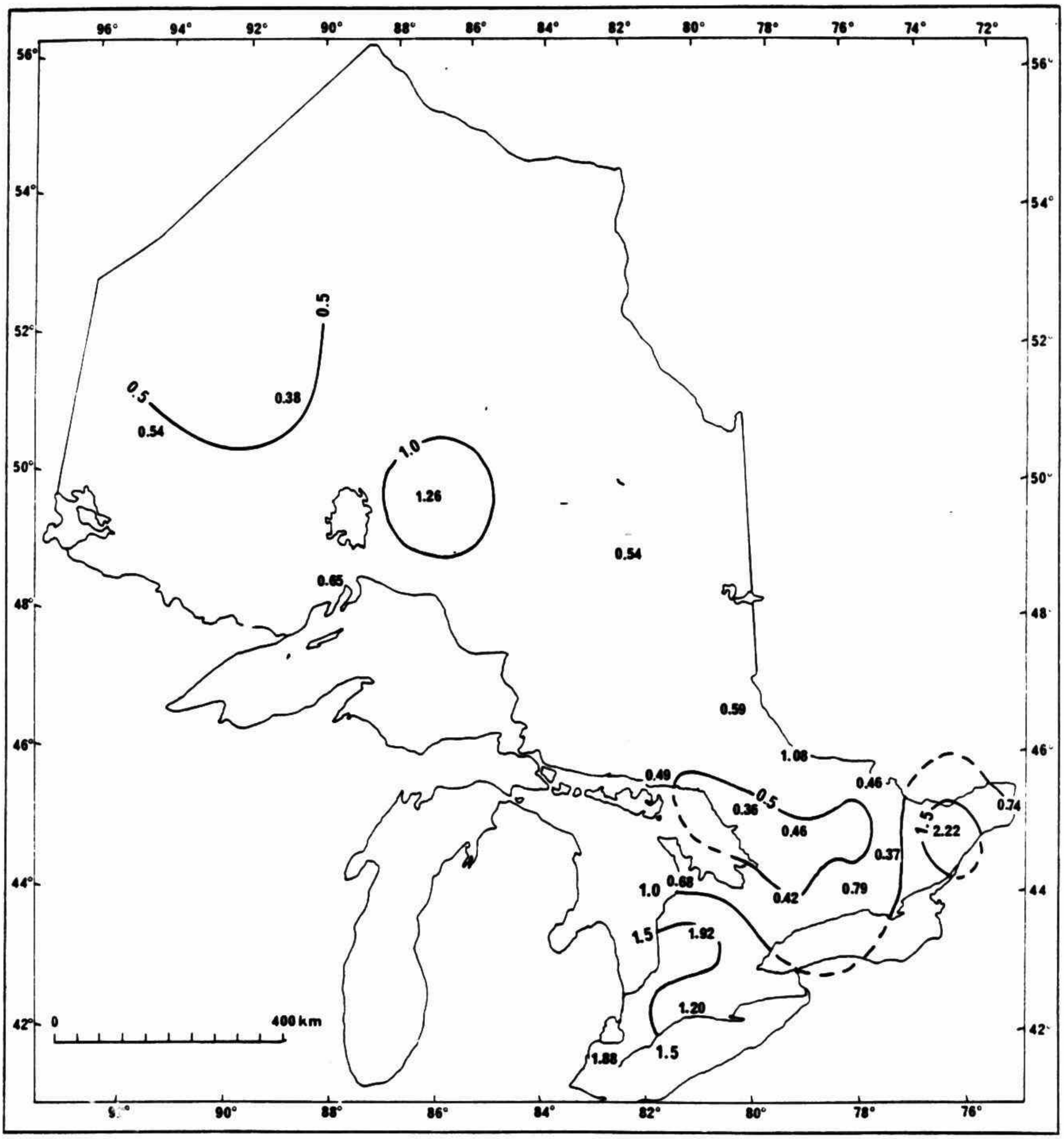

Figure 12: 1982 Annual Average Air Concentration of Mg (0.1 ug m^{-3})

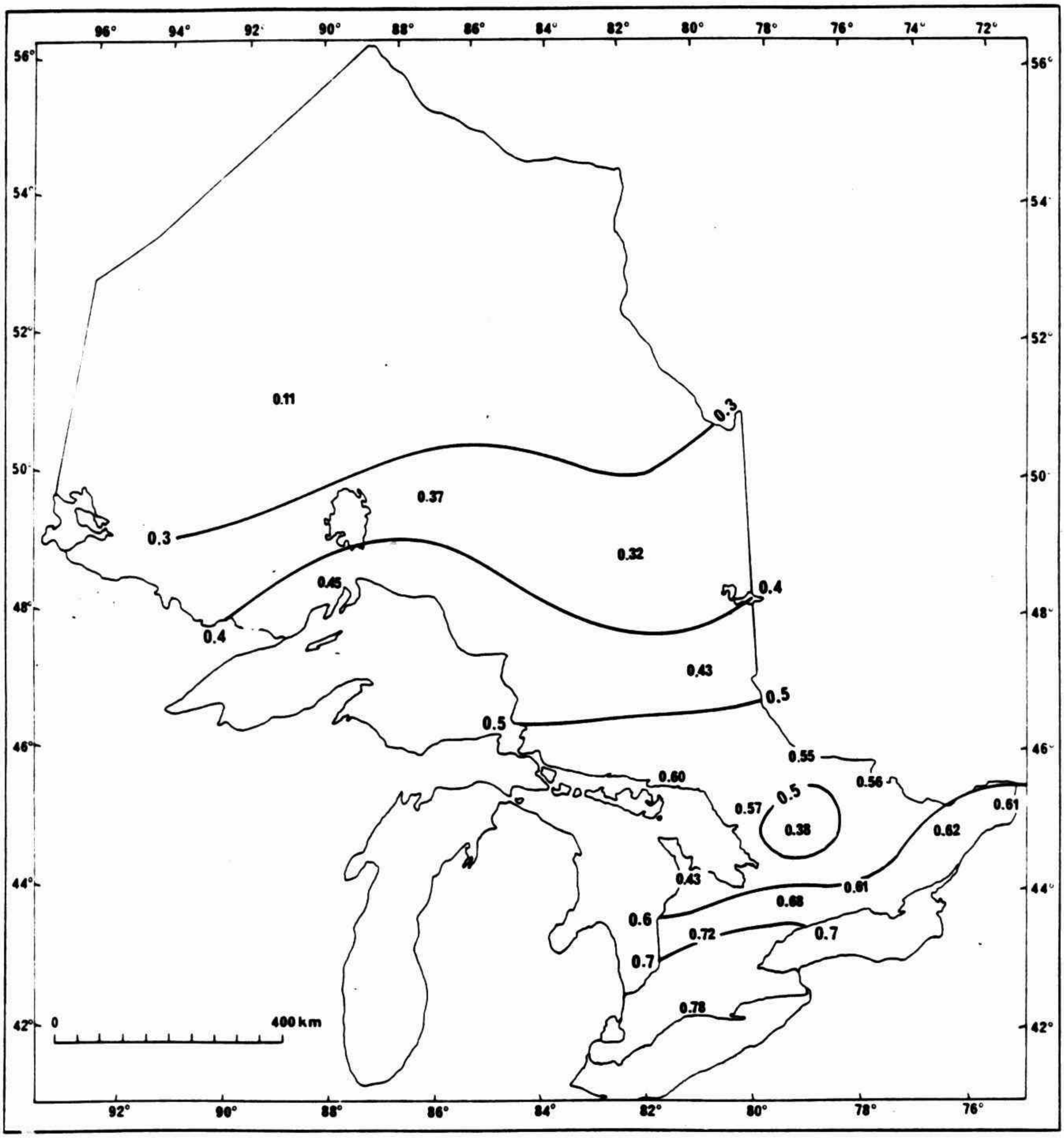

Figure 13: 1982 Annual Average Air Concentration of K (0.1 ug m^{-3})

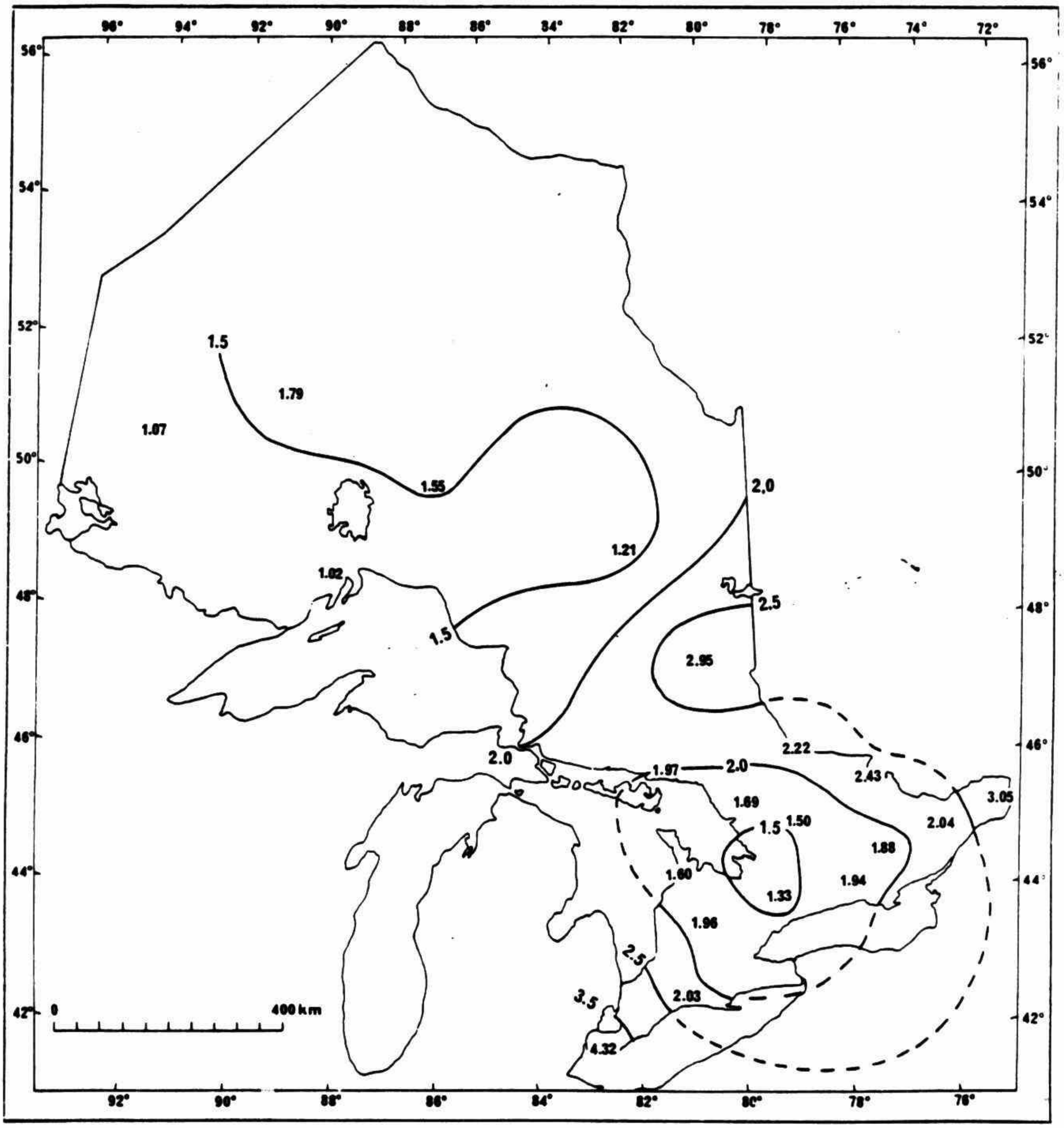

Figure 14: 1982 Annual Average Air Concentration of Cu (ng m^{-3})

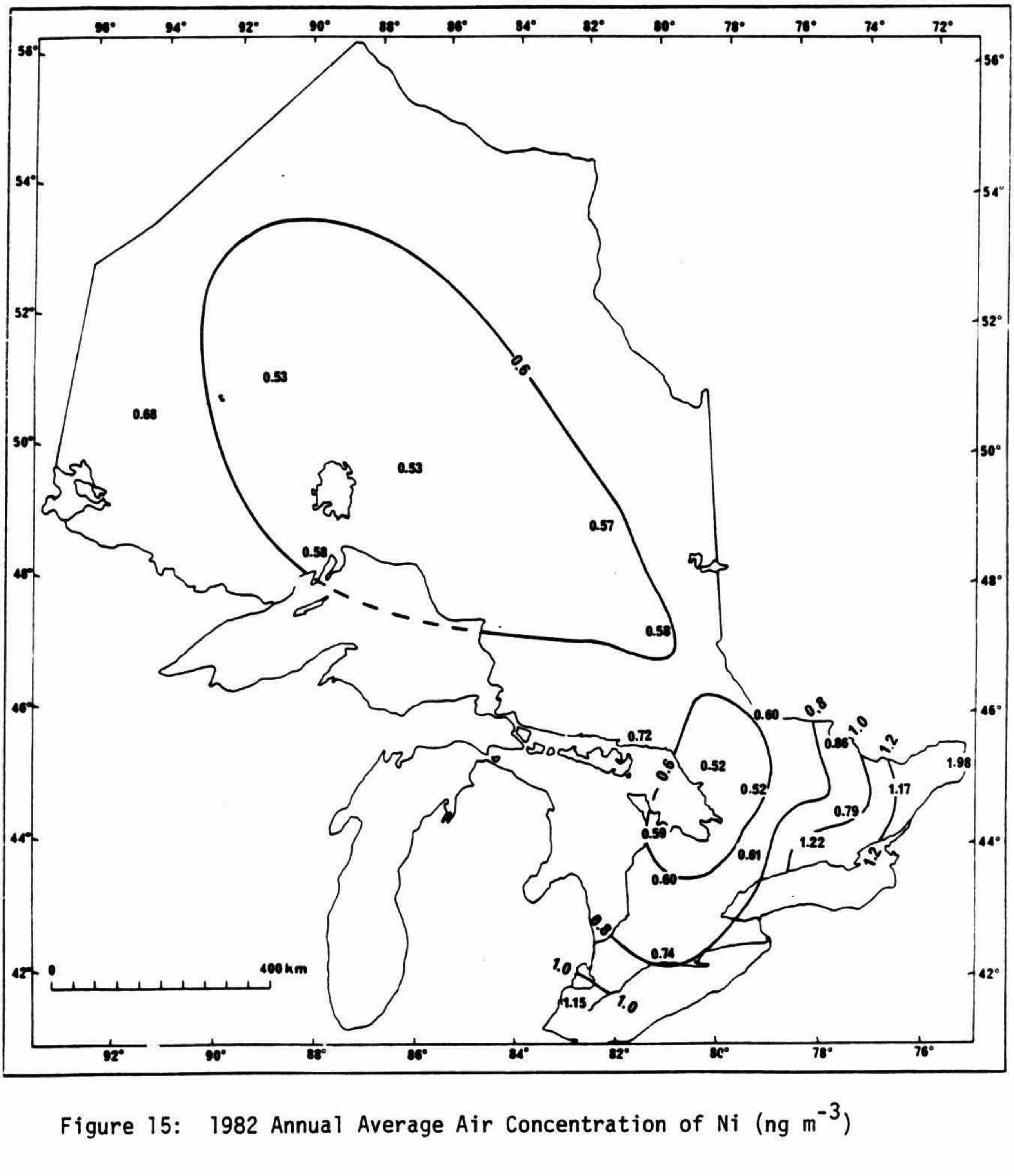

Figure 15: 1982 Annual Average Air Concentration of Ni (ng m^{-3})

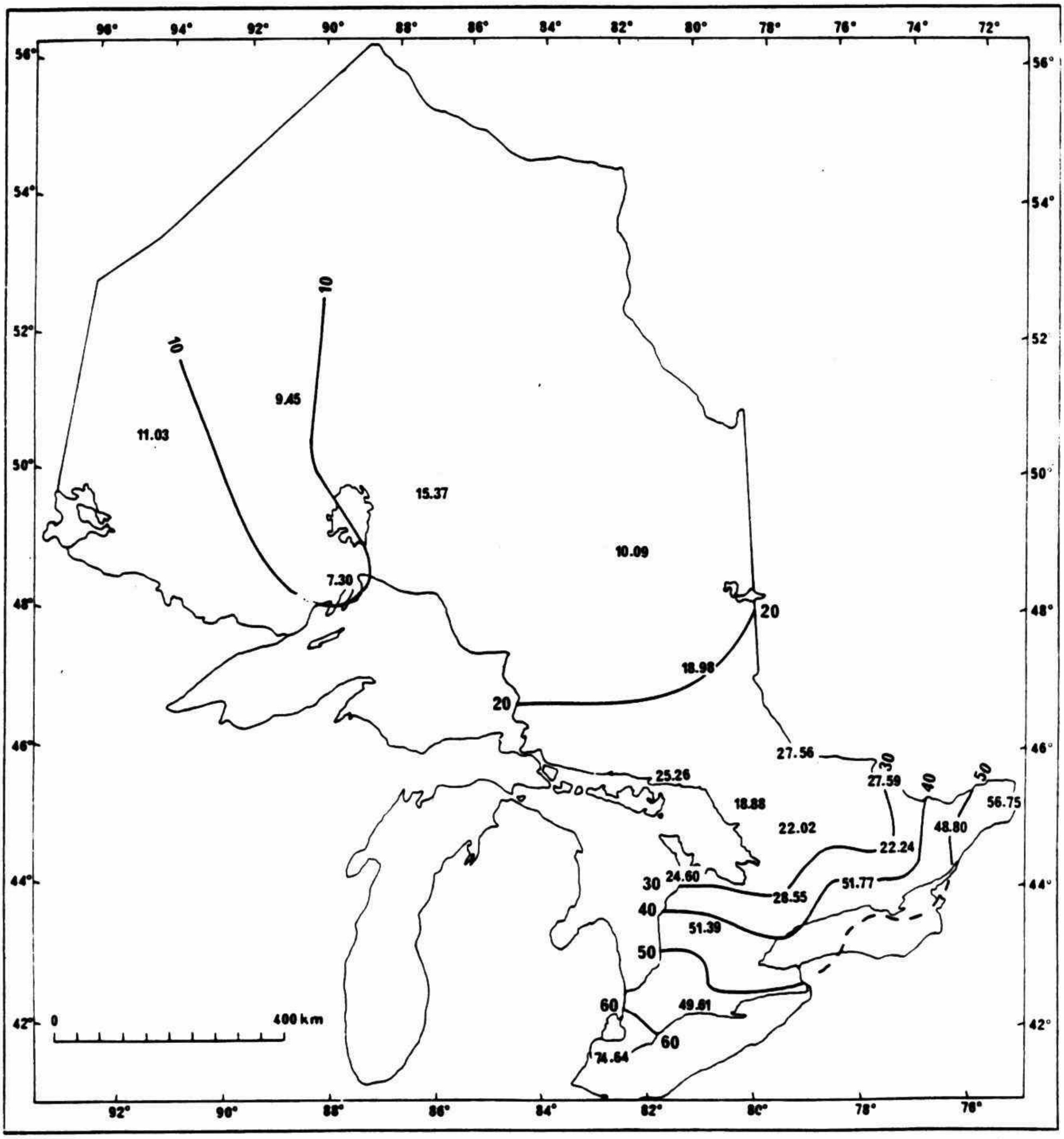

Figure 16: 1982 Annual Average Air Concentration of Pb (ng m^{-3})

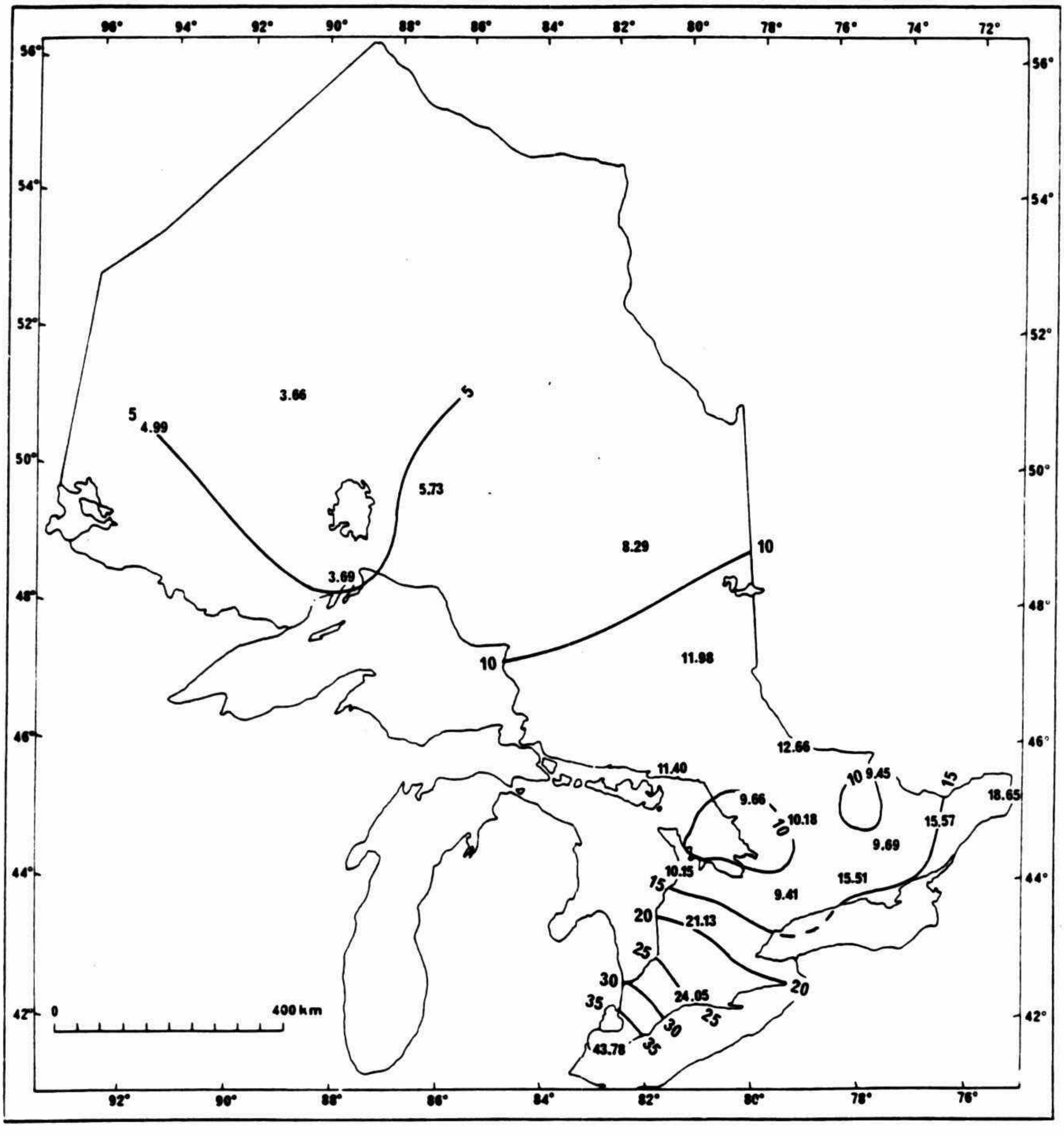

Figure 17: 1982 Annual Average Air Concentration of Zn (ng m^{-3})

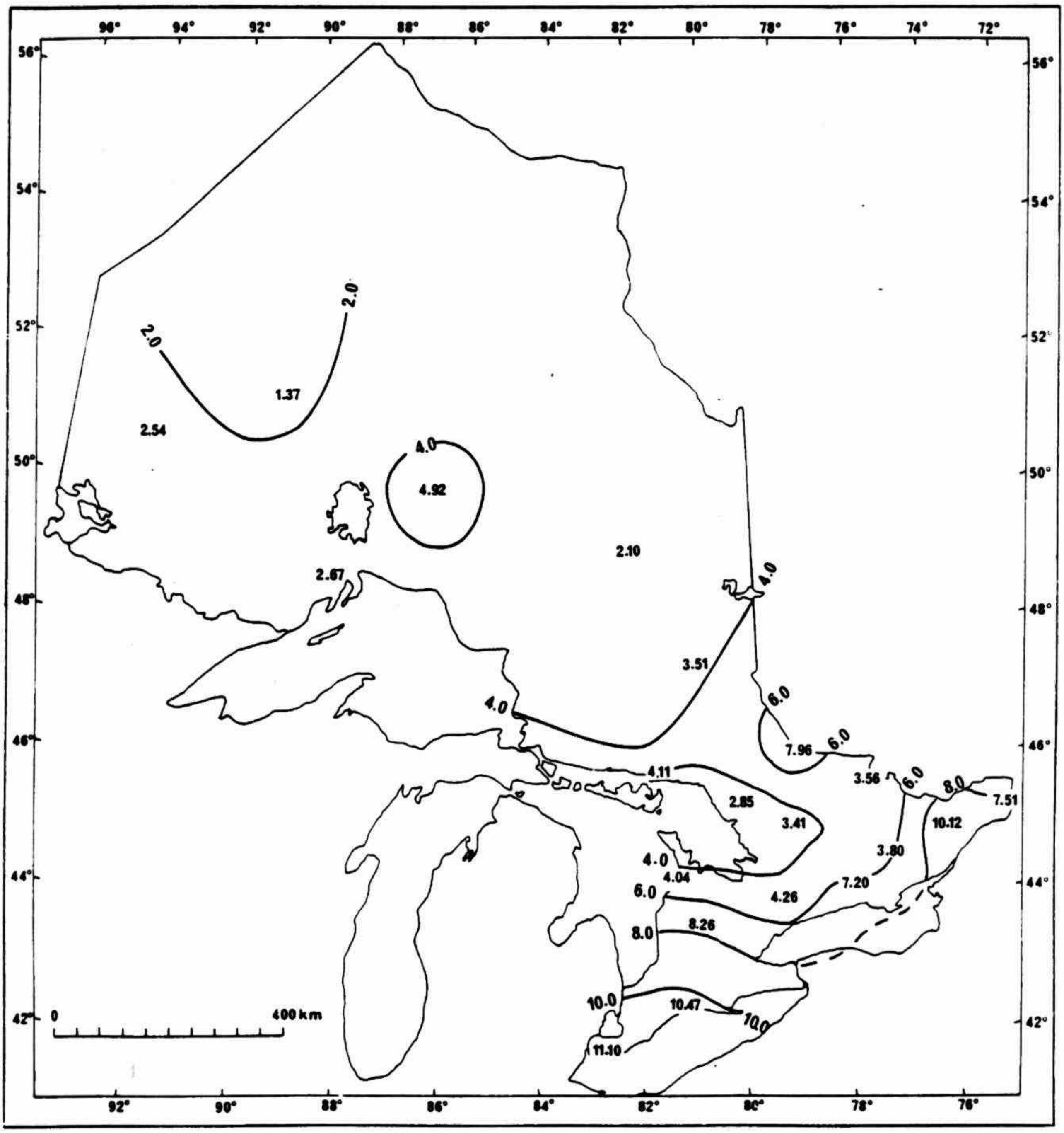

Figure 18: 1982 Annual Average Air Concentration of Mn (ng m^{-3})

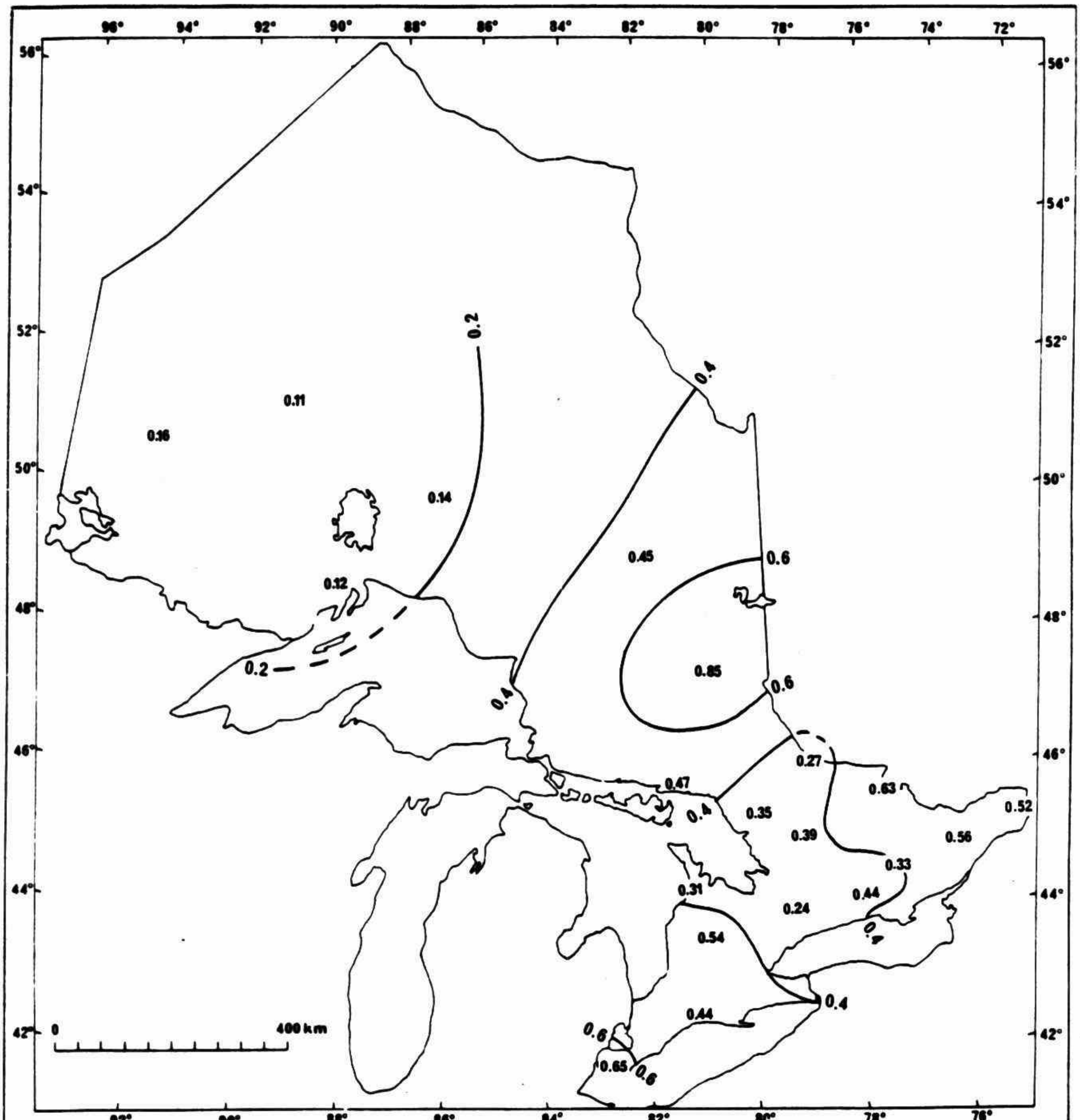

Figure 19: 1982 Annual Average Air Concentration of Cd (ng m^{-3})

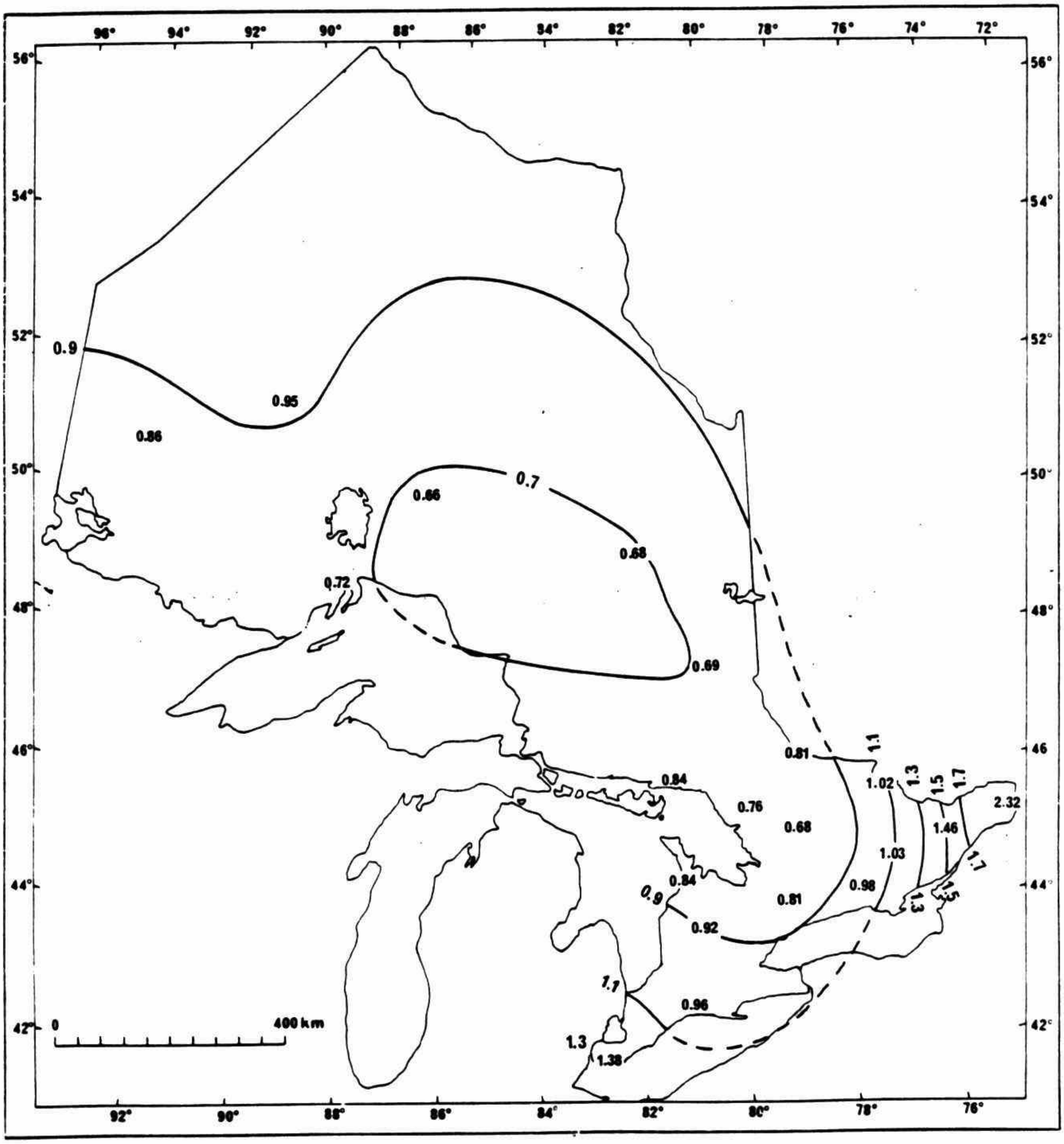

Figure 20: 1982 Annual Average Air Concentration of V (ng m^{-3})

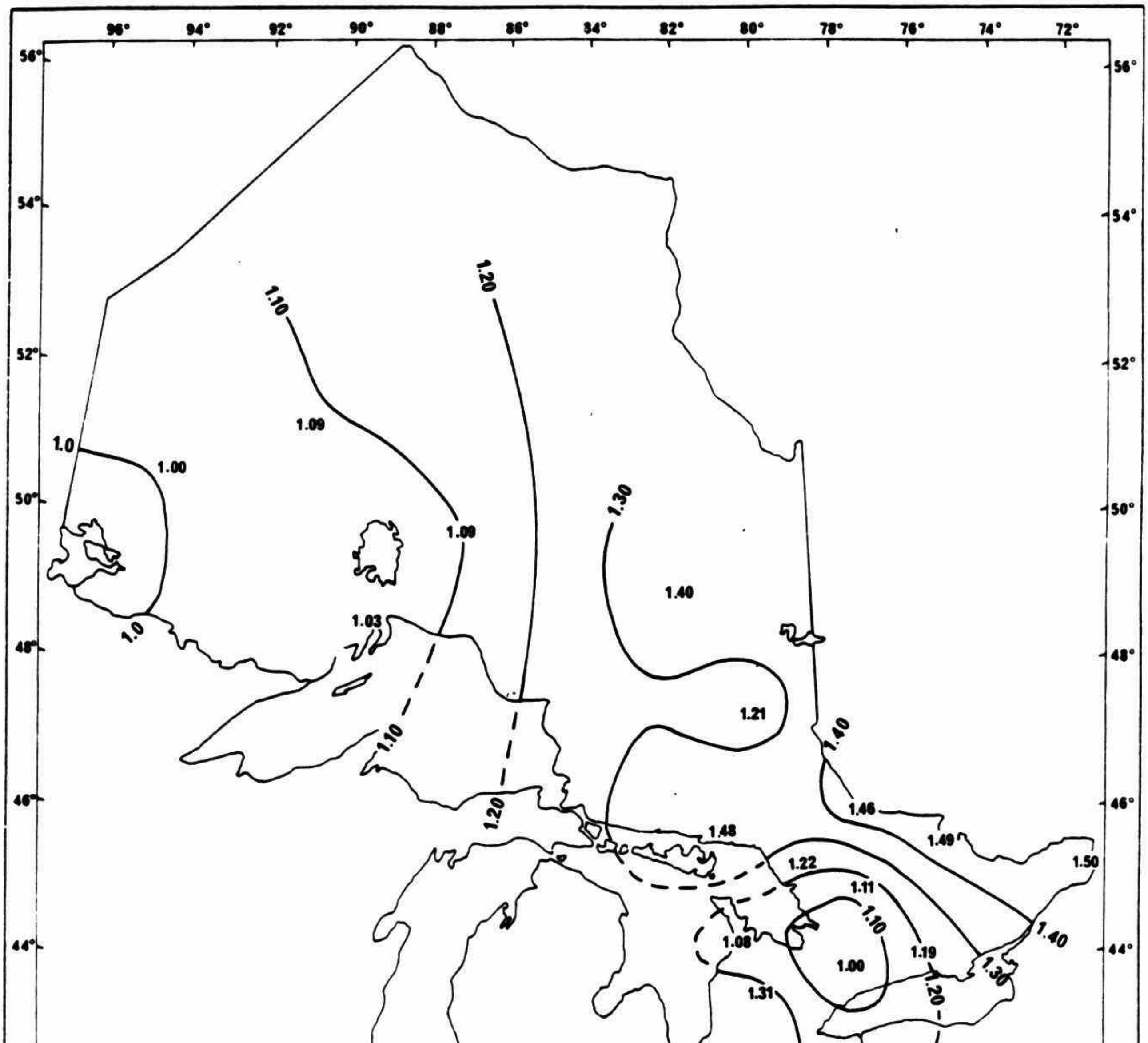

Figure 21: 1982 Annual Average Air Concentration of Na (0.1 ug m^{-3})

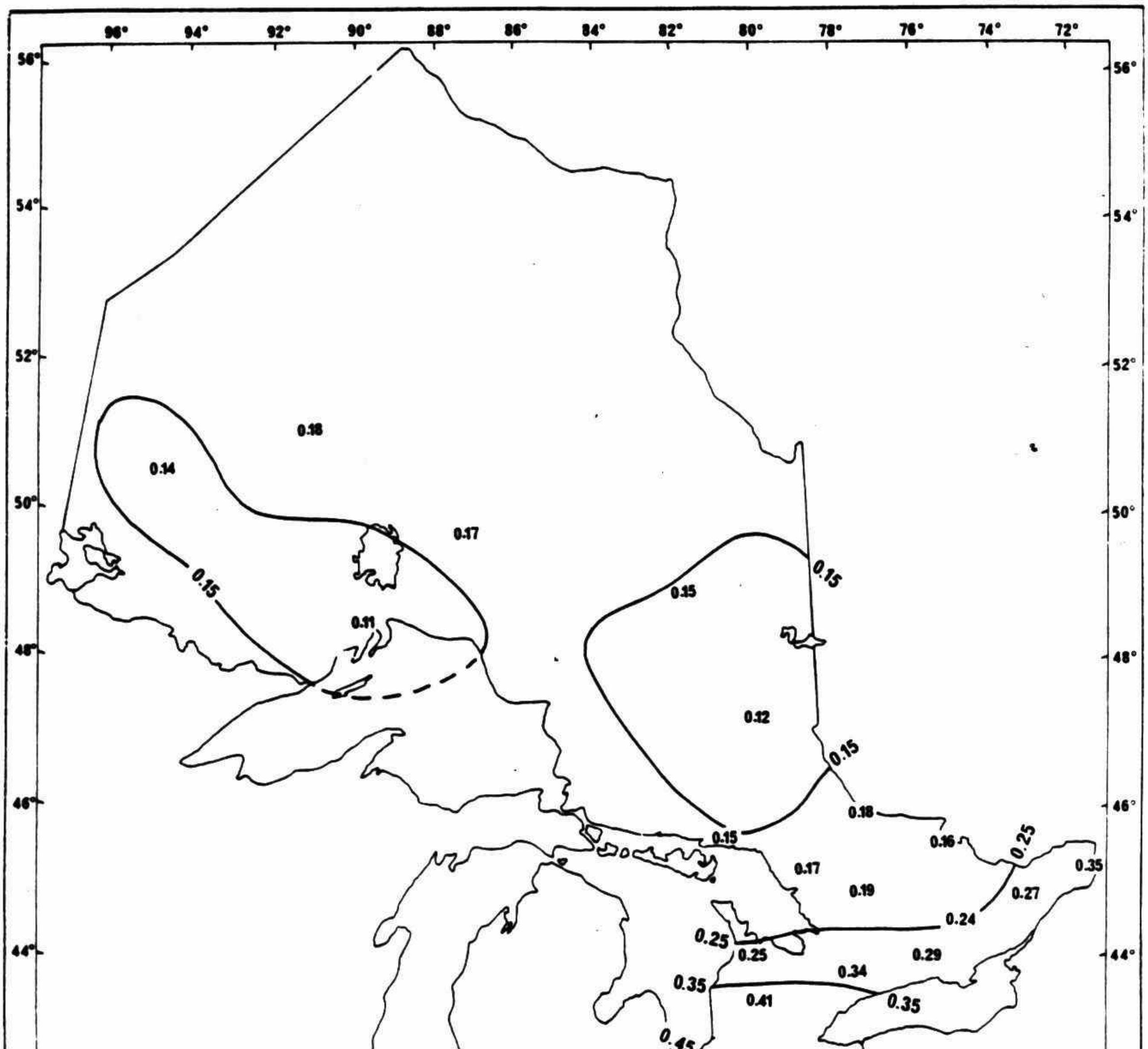

Figure 22: 1982 Annual Average Air Concentration of Cl (ug m^{-3})

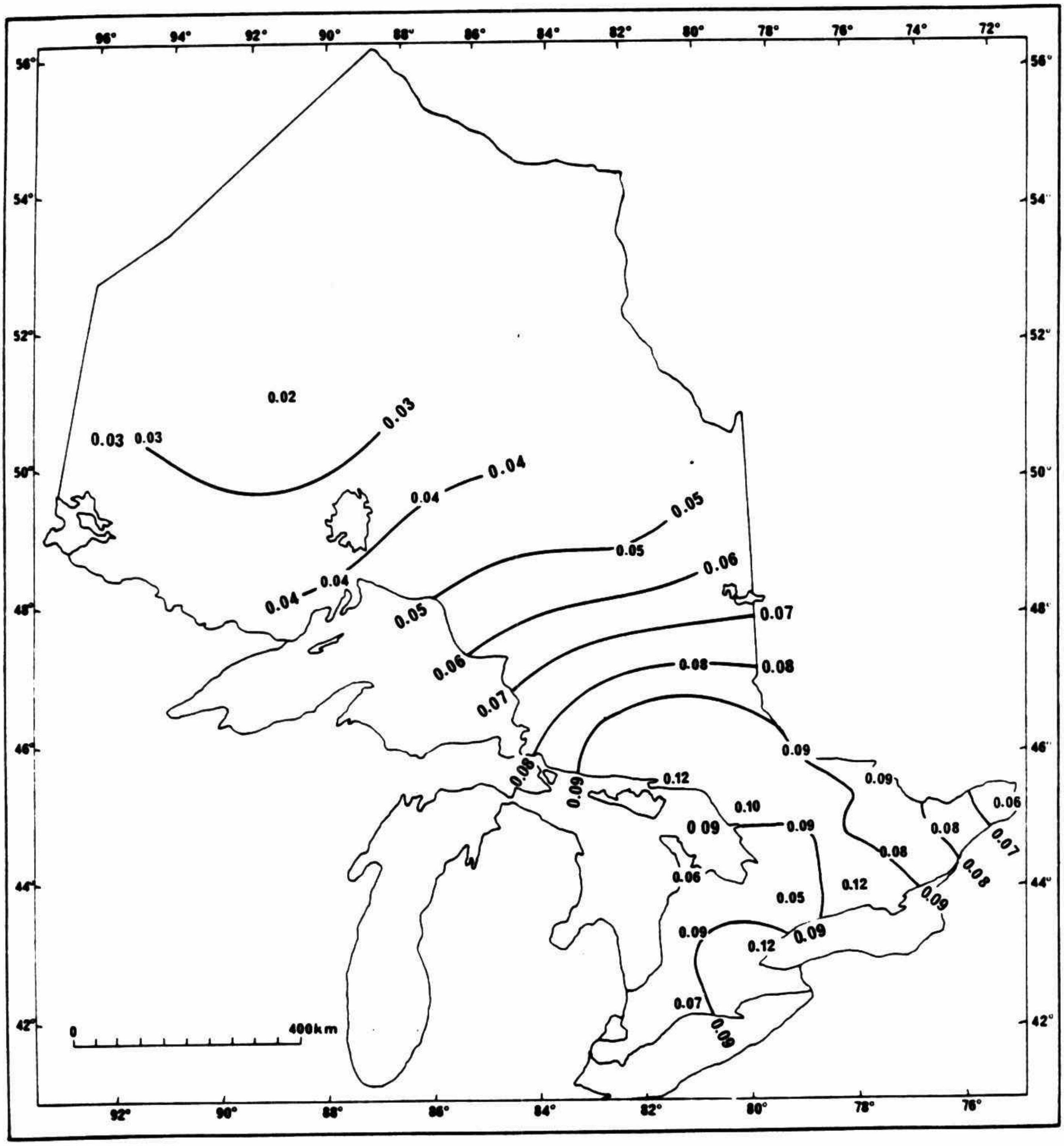

Figure 23: 1982 Annual Dry Deposition of SO_4 = (gS $m^{-2}y^{-1}$)

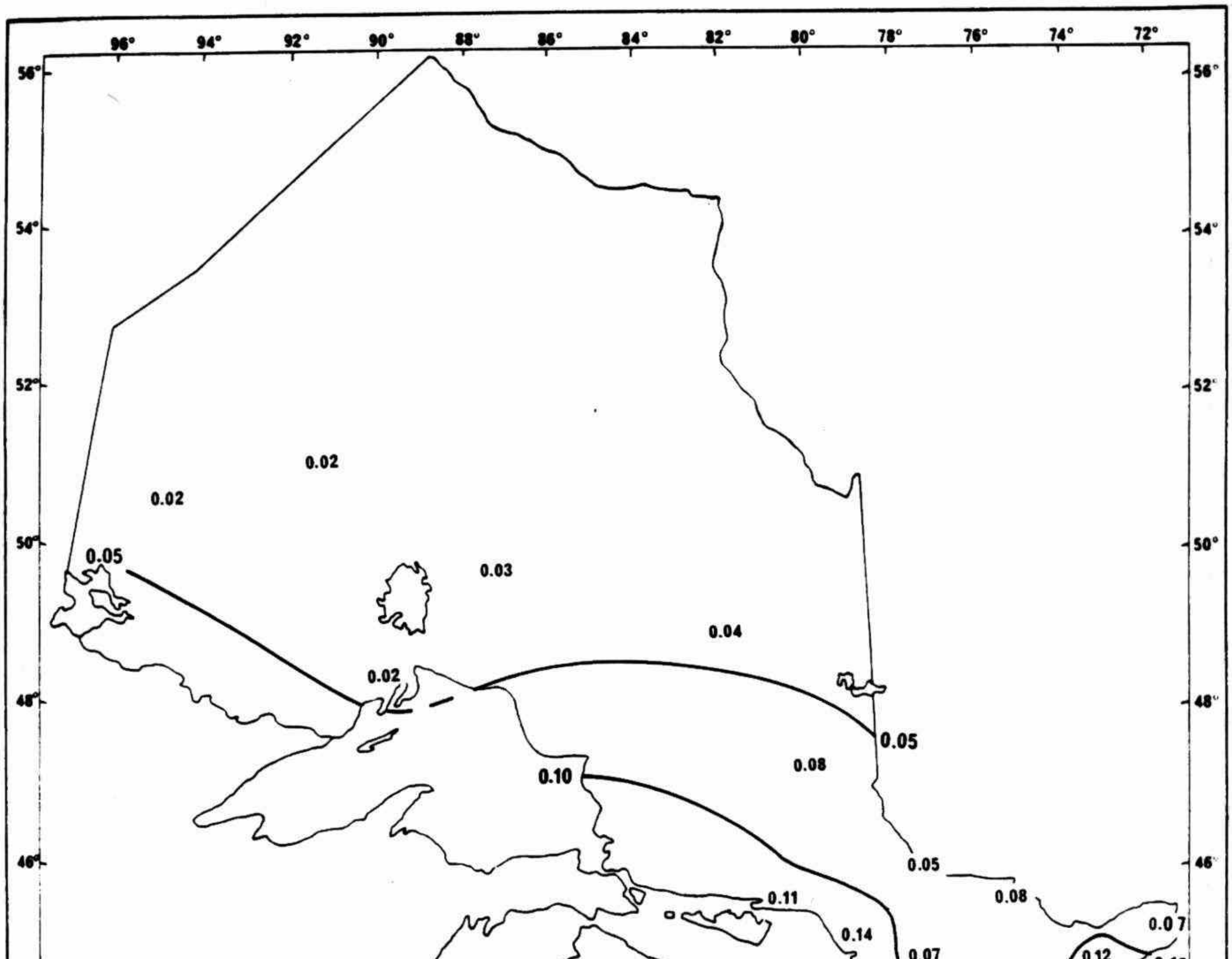

Figure 24: 1982 Annual Dry Deposition of SO_2 ($gS\ m^{-2}y^{-1}$)

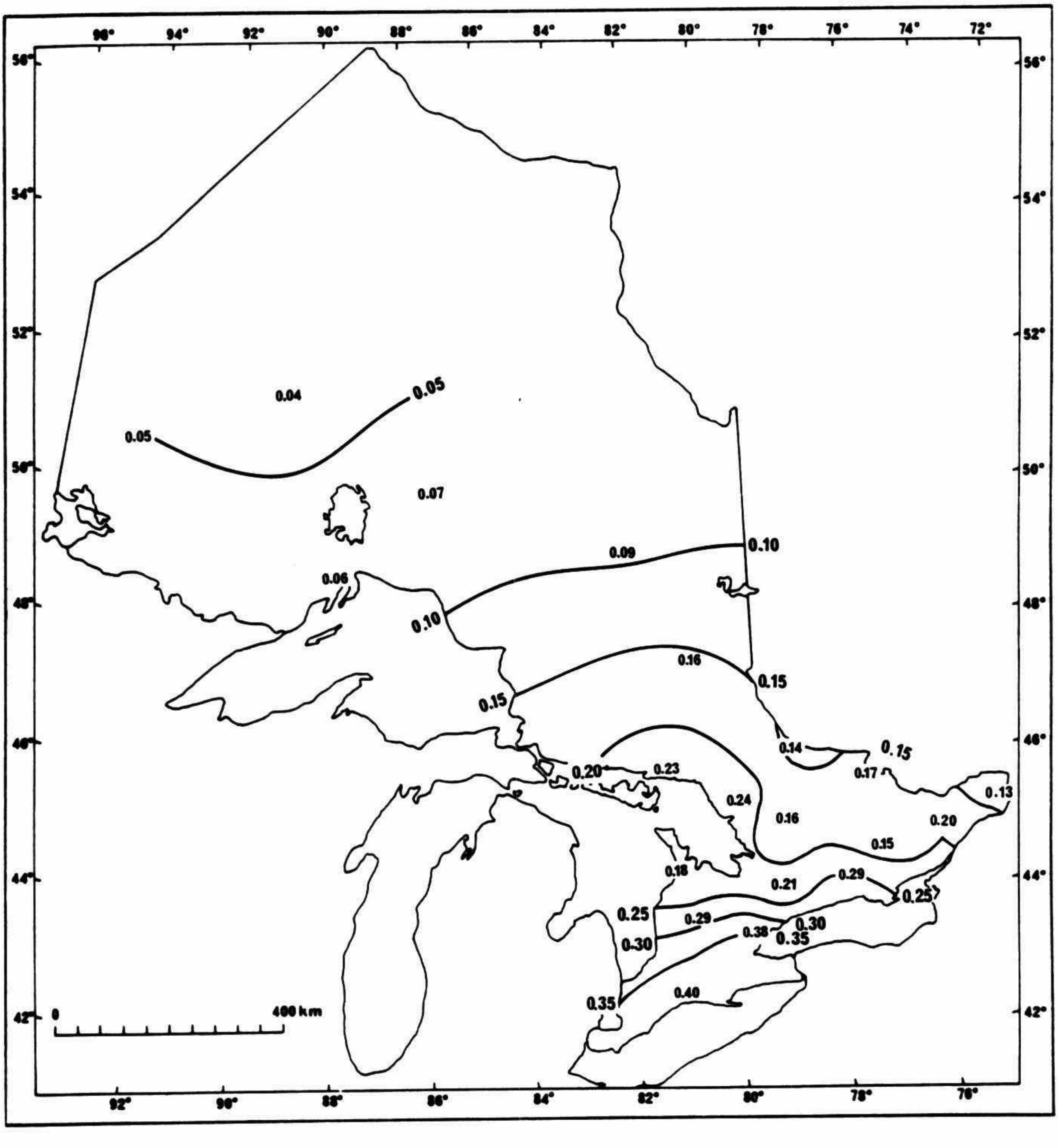

Figure 25: 1982 Annual Dry Deposition of Sulfur (g $m^{-2}y^{-1}$)

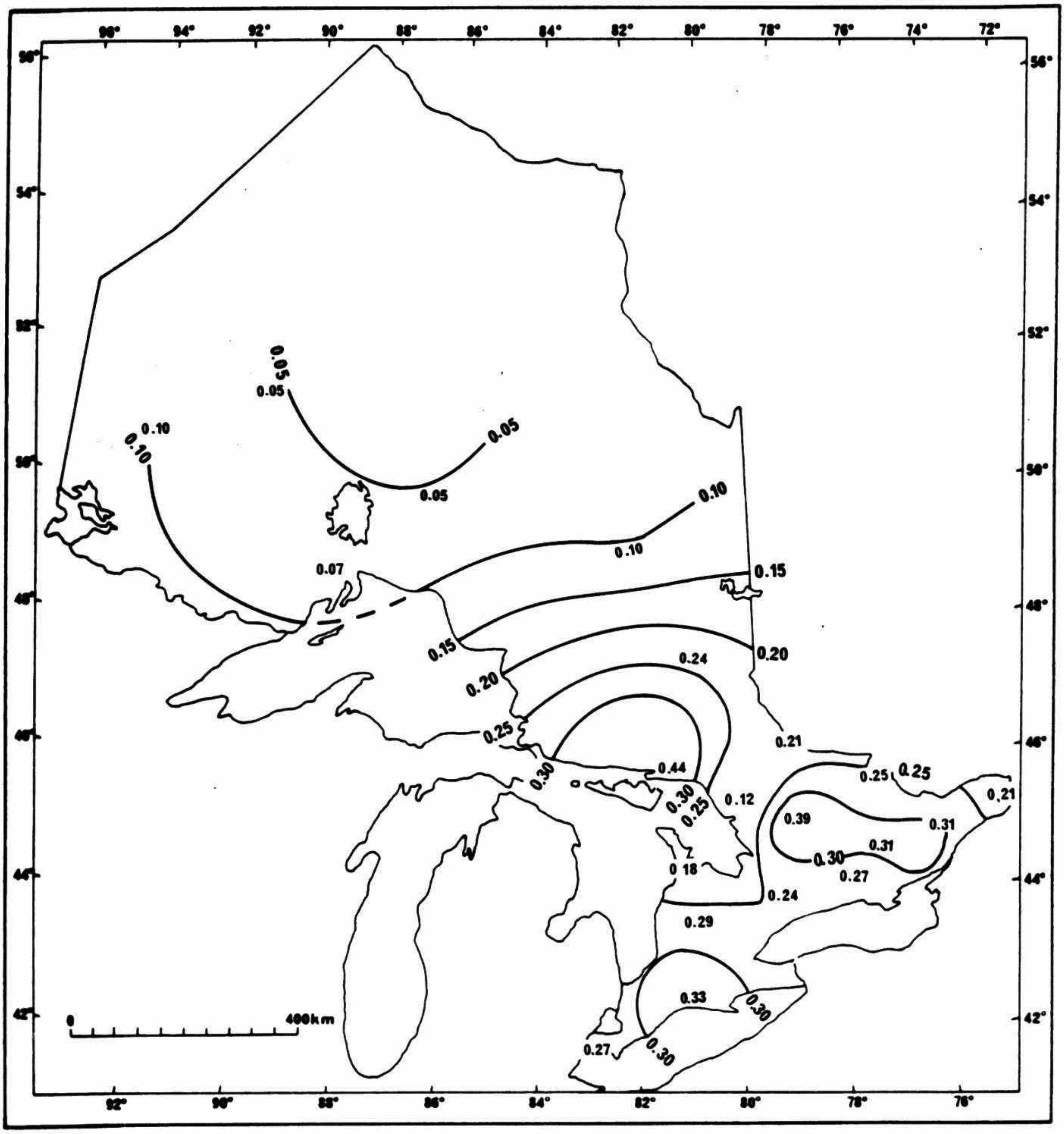

Figure 26: 1982 Annual Dry Deposition of NO_3 (gN $m^{-2}y^{-1}$)

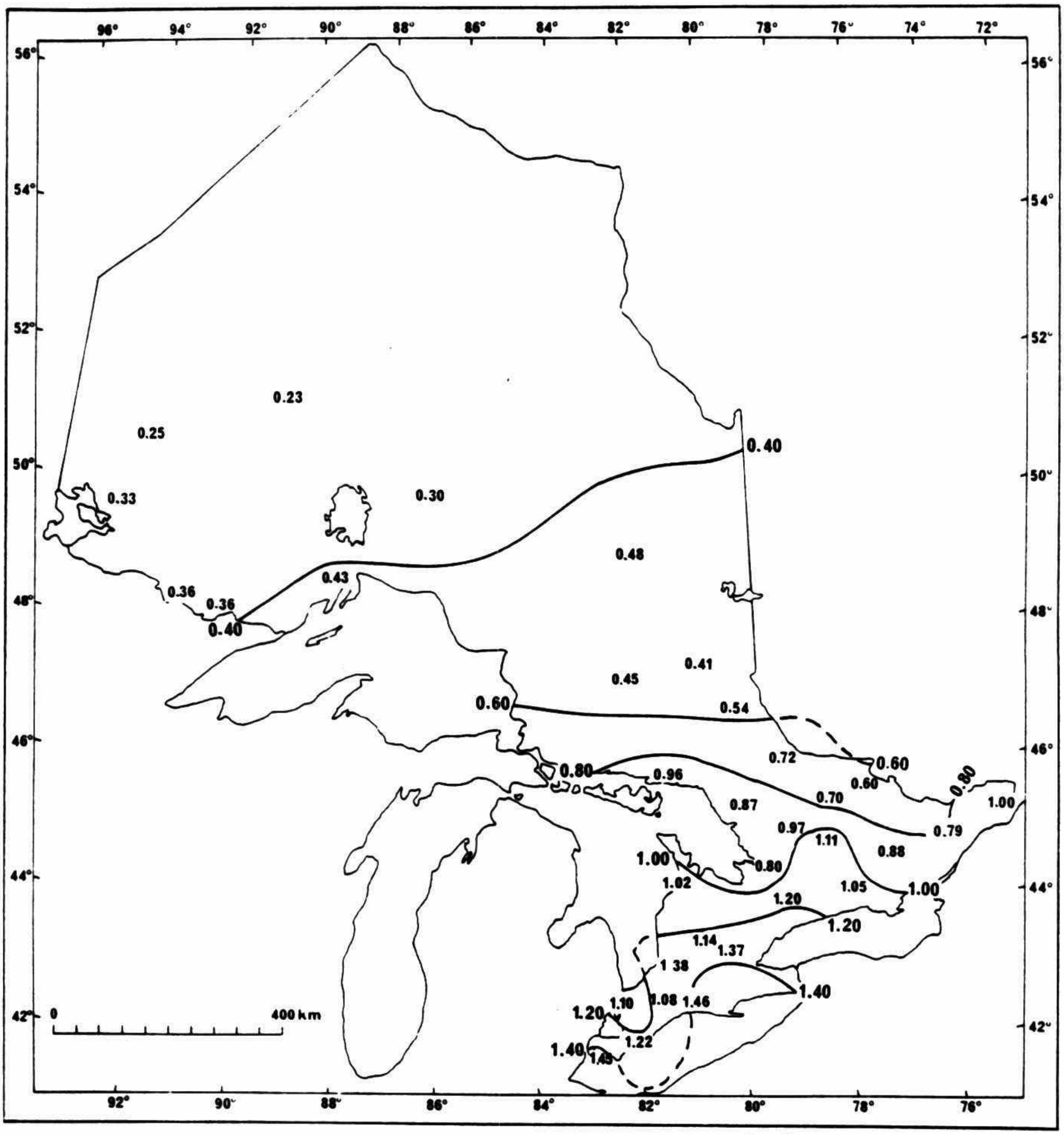

Figure 27: 1982 Annual Wet Deposition of $SO_4^=$ ($gS\ m^{-2}y^{-1}$)

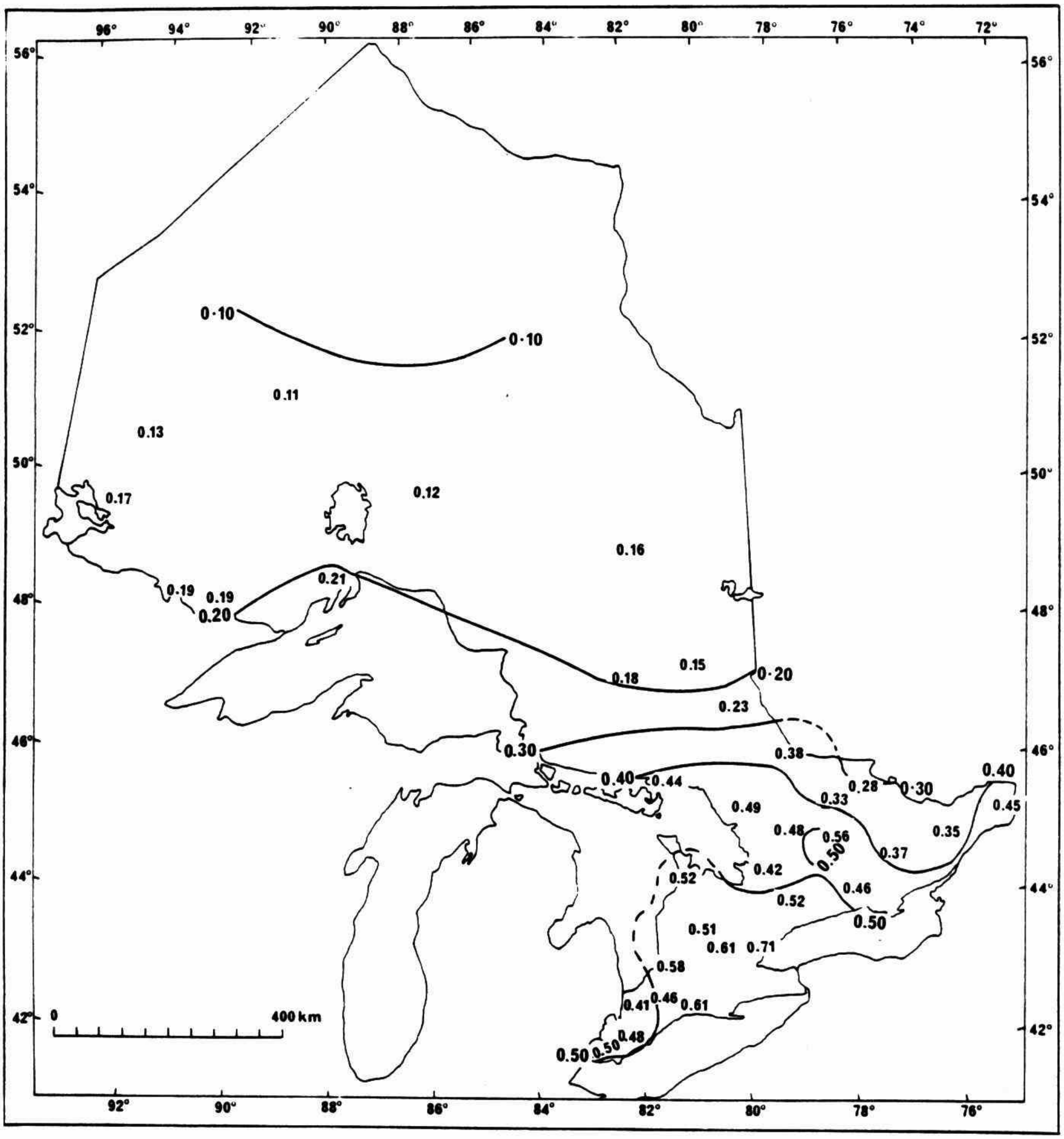

Figure 28: 1982 Annual Wet Deposition of NO_3 ($gN\ m^{-2}y^{-1}$)